University of Edinburgh.

THESIS

for

Degree of Doctor of Philosophy (Ph.D.).

"Ventilation in Mines, with Special Reference to Mine Resistance and Fan Efficiencies".

by

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BOOK I.

Experiments at Mines, with Reference to Mine Resistance.

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INTRODUCTION.

Until very recently the Theory of Mine Ventilation has been a subject which most investigators have neglected very badly. Two men, however, cannot be included among them, viz., Atkinson and Murgue, both having contributed classical works. Rateau was another who may be excluded. Nevertheless this does not imply that Mine Ventilation had been neglected in practice. On the contrary, during the period of these disastrous explosions in the eighteenth and nineteenth centuries, the necessity was felt for a plentiful supply of air in mines at any cost. This need was fulfilled by the use of fans; but, effective ventilation was never coupled with efficient ventilation. When effective ventilation was realised, contentment seems to have reigned, and the papers of those authors mentioned were accepted complacently. Thus, although the chemistry of ventilation was well investigated, the theoretical side of the question was neglected.

This peaceful state, disturbed by Mr.Clive in 1920, was shattered by Dr.Penman in 1921, when he advocated the abandonment of Murgue's "equivalent orifice" and "orifice of passage", pressing for a direct method of measuring mine resistance, following the electrical engineers' Ohm's Law. His suggestion was seconded by Dr.Parker later in 1921 and amplified in

1923 by the Council of the Institution of Mining Engineers which set up a Committee to prepare a foundation for the very necessary research in Ventilation. In 1925 this Committee issued two Reports, in the first of which after revising and summarising previous work, it supported Dr.Penman in his suggestion and fixed standards of measurement; in the second, it pointed out the effects of natural ventilation in the ventilation of deep mines. Various other people, notably Professors Briggs and Hay, have also agreed with Dr.Penman.

In the discussions on the recent papers by the modern writers just mentioned, many laws, modifications of Dr.Penman's variation of Ohm's Law, have been suggested, especially by Professor Briggs, to give some criterion of mine resistance. However, no law or equation seemed favourable to all; there seemed nothing but doubt on every point.

In an endeavour to throw some light on this clouded subject, tests were run on various collieries in Scotland and England by Professor Henry Briggs, D.Sc., Ph.D., etc., J.N.Williamson, B.Sc., Ph.D., J.S.Penman, B.Sc., Ph.D., and the writer. The results of this investigation will be described later. It is now necessary to give a fuller account of previous allied work, to which this fragment is added.

Before reviewing this work, it is the writer's privilege to thank the various Coal Companies and their

Officials, especially their Managers and Pit Staffs, as only by their collaboration and kind assistance was the enquiry made possible. Others, especially Dr.J.N. Williamson and Dr.J.S.Penman have the writer's best thanks for their able assistance. A special acknowledgement is due and gratefully accorded to Professor Henry Briggs, under whose guidance and direction the experimental work was carried out, for his kindly interest as well as invaluable supervision on any and every occasion. Finally, the great assistance given by the grant from the Coalowners' Research Association for travelling expenses is also acknowledged.

PART I.

A REVIEW OF RECENT RESEARCH WORK IN CONNECTION WITH MINE VENTILATION.

Penman's Work.

In this section, some of the previous allied work is reported in some detail. As Dr.David Penman is the modern originator of the revolt from coma as regards the Theory of Mine Ventilation, it is fitting that his important paper should be considered first. Called "A New Method of Measuring Ventilating Resistances with Special Reference to the Operation of Fans in Combination", it was read before the Mining Institute of Scotland in August 1921. Its purpose was "two-fold, namely:-

1. To suggest a method of measuring the ventilating resistances of mines and fans, based on analogies drawn from electric circuits.

2. To employ this method in calculating the probable performances of duplicate ventilating plants, where two or more fans are run together in series or in parallel combination".

Penman pointed out that, although Mr.H.W.G. Halbaum and others had suggested a similarity between the flow of electricity in a conductor and the flow of air in an airway, the analogy could be used to a much greater extent. A fan ventilating a mine was comparable with a dynamo producing an electric current in resistances, and, consequently, the laws of electricity might, in a modified form, be applicable to ventilation.

$$I = \frac{E}{R + r}$$

where I amperes was the current.
E volts was the electromotive force.
R ohms was the resistance of the external circuit.
and r ohms was the internal resistance of the dynamo.

From this, $Q^2 = \frac{H}{R + r}$ could be derived,

where H inches of water was the total depression produced by the fan, subdivided to
h_m for the mine
h_f for the fan
R was the resistance of the mine
r was the resistance of the fan
and Q was the quantity of air flowing

but no units would be defined yet. The term Q^2 did not closely follow the analogy, because in ventilation the pressure was proportional to the square of the quantity, not directly proportional as in electricity. To link up with the "Equivalent Orifice Theory", a formula could be given, namely:-

$$\frac{1}{a^2} = cR$$

where a was the "equivalent opening"
and c was a constant, depending on what units would be used.

This method was applied to the running of mine fans in series and in parallel, basing his application upon electric machines under these circumstances. Resistances were also considered, giving

$R = r_1 + r_2 + r_3 +$ etc for resistances in series

and $\frac{1}{\sqrt{R}} = \frac{1}{\sqrt{r_1}} + \frac{1}{\sqrt{r_2}} + \frac{1}{\sqrt{r_3}} +$ etc for resistances in parallel

Considering two equal resistances in parallel, if $r_1 = r_2$,

$$R = \frac{r}{4}$$

With two fans in series producing h_1 and h_2 inches of water-gauge and having internal resistances r_1 and r_2, R being the mine resistance,

$$Q = \sqrt{\frac{h_1 + h_2}{R + r_1 + r_2}}$$

If $h_1 = h_2 = h$, and $r_1 = r_2 = r$

$$Q = \sqrt{\frac{2h}{R + 2r}}$$

With two fans in parallel,

$$Q = \sqrt{\frac{h}{R + r}}$$

The aero-dynamic efficiency ratio for a single fan system would be given by $\frac{R}{R + r}$; for a system ventilated by two identical fans, if in series by $\frac{R}{R + 2r}$ and if in parallel by $\frac{R}{R + \frac{r}{4}}$.

Variations of the fan speeds in the parallel arrangement, and the shape of the blades were discussed. In addition the description and results of a series of tests carried out on running in parallel two fans (Waddle and Sirocco) at Wellesley Colliery, Fife, as well as a comparison of other two similar tests in Yorkshire were given.

Penman gave the following conclusions:-

1. The advantage to be gained by two or more fans in series or in parallel depended chiefly on the relation existing between the resistance of the fans and that of the mine.

2. Unless the resistance of the fan was small compared with that of the mine, the operation of two fans in series would result in a greatly lowered efficiency.

3. Unless the resistance of the fan was at least one third of the resistance of the mine, the advantage of running two fans in parallel was small.

4. If the resistance of the fan was small compared with that of the mine, not only would the increase of quantity by parallel operation be small, but a slight reduction or increase in the speed of one of the fans over the other would result in the air being reversed in that fan which ran at the slower speed.

5. If increase of quantity was the sole desideratum, better results would in most cases be obtained by combining the fans in series than by running them in parallel.

6. The increase of quantity obtained by running two similar fans in series at the same speed at which they would run singly would in most cases be approximately 35 per cent.

7. The increase of quantity obtained by running two similar fans in parallel would range from 5 per cent.to 15 per cent.in the majority of mines in Great Britain.

8. The satisfactory running of two fans in parallel would best be accomplished through the medium of synchronous electric motors.

9. If two fans were running in parallel and the speed of one should fall to any extent, the other fan might become dangerously overloaded, unless there was a large margin of power available in the motor or engine driving it.

The discussion on this paper was very keen, the main note being one of congratulation and eagerness to use the ideas brought to light again.

Penman was the joint author with his brother, Dr.J.S.Penman, of "Experiments on the Flow of Air in Mines", read before the same body in October 1924. In this communication, it was pointed out that two modes of flow of a fluid filling a duct could be defined:- stream-line and turbulent, the change from the one to the other occurring at the "critical velocity", which would be given by the expression

$$\frac{\delta V_c D}{\eta} = \text{constant},$$

where δ = density of fluid.

V_c = critical velocity.

D = diameter of duct.

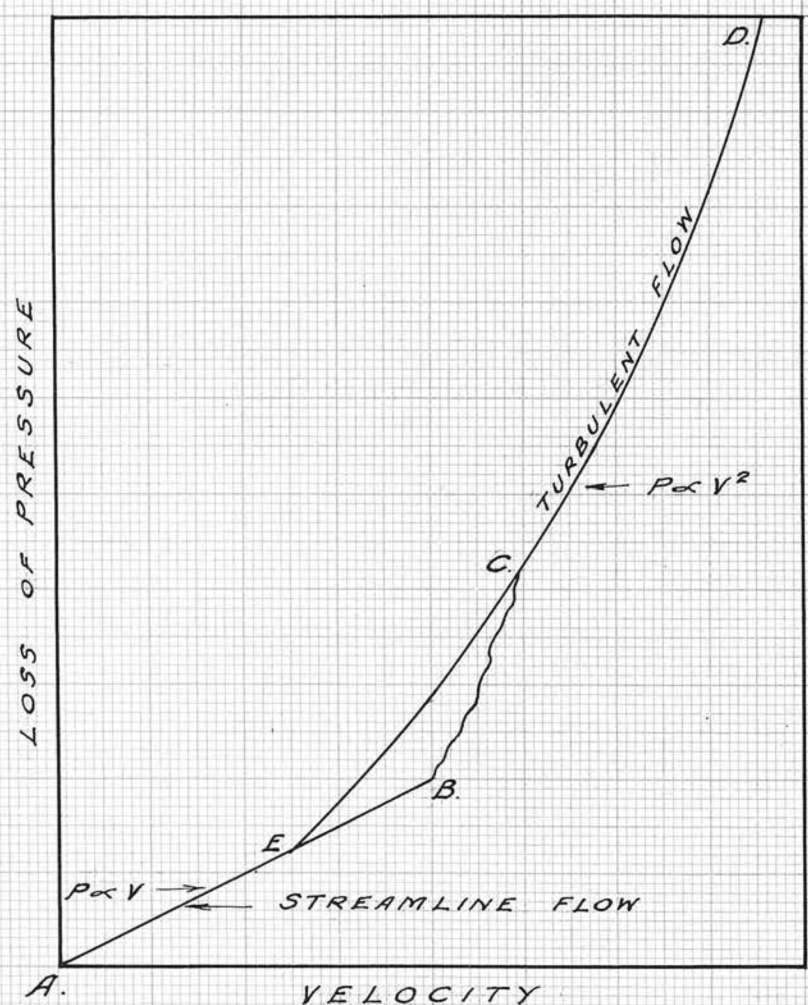


FIGURE 1. — RELATION BETWEEN VELOCITY AND PRESSURE.

η = coefficient of viscosity,
and the constant was
Reynold's constant having
two values,

one for the point of change from stream-line to turbulent flow, the other for the point of change from turbulent to stream-line flow. For stream-line flow $R = KV$, and for turbulent flow, $R = K\ V^n$, where R = frictional resistance to the flow of air, V = velocity, K = a coefficient and n = an index, i.e.a number. Figure 1.would show this relationship.

According to Lacey[1] for pipes.

[1] "Flow of Gas in Pipes", Procs.Inst.Gas Engineers,1923.

$V_c = \frac{0\cdot 36}{D}$ feet per second where D was in feet. Considering the relationship of pressure and quantity, he also found that for stream-line flow, the index was one, whereas for turbulent flow, it was approximately two. Storrow[2] experimented

[2] Trans.Inst.M.E. 1917-1918, Vol.LV, p.313,

on air passing through tubes packed with coal, and found that the index was one. Like results under similar conditions had been found by the Penmans themselves, who also found indices of 2·08, 2·1, and 2.15 at a right angle bend, and an index of 2.25 at a contraction in a four inch tube.

Tests carried out by them at Wellesley Colliery, Fife, gave an index of 1.8 and showed that neglecting natural ventilation, the resistance of the mine was constant for all practical purposes and within the limits of observation. An interesting result could be derived thus:-

W.G. $\propto$ Quantity$^{1.8}$

and W.G. $\propto$ Speed^{2}

$\therefore$ Speed $\propto$ Quantity$^{0.9}$

i.e.the quantity would increase at a slightly greater rate than the speed of the fan.

They concluded that in mine passages there were stream-line flow and turbulent flow, following the laws $P = C_1 V$ and $P = C_2 V^n$ respectively; and where both existed together, $P = C_1 V + C_2 V^n$ was the law. $P = C_1 V$ would hold for closely packed goaf and in smooth sided galleries where the velocity was low enough. Generally, however, $P = C_2 V^n$ would be correct, with n approximating to the value two, but, in most cases, a little less. For mine calculations, turbulent conditions should correctly be assumed, and a single value of n should give a very close approximation to the conditions holding. Therefore, a suitable equation for the loss of pressure in an airway or in a whole mine would be $P = RQ^n$, where n probably had a value between 1.8 and 2.0.

Discussing this last contribution, Parker pointed out that the index would generally have the higher value and emphasised the loss in neglecting natural ventilation; Hay criticised the choice of the anemometer as the flow-meter and championed the direct unit of resistance in face of Adams, who stated that three units would be required, one for each type of flow, namely, stream-line, turbulent and mixed.

Clive's Work.

Previous to Penman's contribution to Mine Ventilation, Mr.Robert Clive had revived some interest in the subject in March 1920, when he wrote a paper "Running Two Fans in Parallel at Bentley Colliery, and other Ventilating Problems". This paper was delivered before The Midland Institute of Mining, Civil and Mechanical Engineers with the object of providing "subjects for discussion on (1) The practicability of running two fans in parallel; (2) the variable frictional resistance of the mine taken over a long period; and (3) the effect of natural ventilation and varying surface temperature with deep shafts".

After describing the ventilation plant and arrangements at the colliery, he gave the results of tests on the two fans running in parallel; he showed that he obtained an increase in the quantity of air of 15.3 per cent, of watergauge of 37.7 per cent, and of total indicated horse power of 54.3 per cent compared with only one fan running. Also, each engine developed less power than when run singly at the same speed and took approximately half the load. Increased ventilation could be obtained without loss of efficiency when the equivalent orifice of the mine was greater than the orifice of passage of the fan; where this ratio was one or less, in Clive's opinion, the results might not be so satisfactory. His exp eriments had proved that the fans need not necessarily run at the same speed to increase the water-gauge and quantity of ventilation. The friction of the mine was appreciably less when the pit was idle, due to a clearer working-face. The fan drift water-gauge required for a given quantity of ventilation varied with deep shafts in relation to the temperature of the downcast. The only usual requirement would be to run the fan at a slightly greater speed in summer than in winter.

The equivalent orifice would vary with the life of the mine, increasing rapidly at first, then more slowly, probably decreasing after the fully developed period was reached. Measurements of the air circulated in the mine by natural ventilation on a cold February day gave 204,800 cubic feet of air per minute, or about two-thirds of the quantity produced when the fan was running.

The discussion was largely as to fan policy - whether to instal fans which could be replaced, or to use some system or arrangement of fans. No really definite scheme was settled however.

Clive expanded his notes on natural ventilation, when, in April 1924, before The Midland Institute of Mining Engineers, he read a paper "The True Effect of Natural Ventilation in Deep Mines, (Second Report of The Midland Institute Committee on the Ventilation of Mines)". The object of the paper was to draw attention to the part played by natural ventilation in assisting the ventilation of deep mines and to indicate some of the factors which were affected. The paper was to deal with mine ventilation from the point of view of practical application - in contrast to Professor Douglas Hay's paper, "The Theory of Mine Ventilation" (read immediately before), which had dealt with the subject from a fundamental basis. It was to show:-

(1) The effect of natural ventilation,

(2) The effect due to shaft resistance and resistance at shaft mouthings, and

(3) Variation due to observation errors, etc.

The effect of Natural Ventilation might be compared to the effect of a second fan in series with the main fan and fixed in the middle of the upcast shaft. The effect was a varying one, due to the variation in the difference in temperature between the two shafts. The effect was small in older mines, but was quite considerable in modern, large, and deep collieries.

Various arrangements of the ventilating system at a Yorkshire Colliery were tested, and the experimental observations were given.

The following conclusions were tabulated:-

(1) In order to obtain the full effective water-gauge producing ventilation in the mines, it was

necessary to add the water-gauge due to natural ventilation to the observed water-gauge in the fan drift (or deduct if the natural ventilation was acting adversely).

(2) To calculate the combined orifice of the mine and shafts, the full effective water-gauge must be used, and not the observed water-gauge.

(3) The quantity of air produced by natural ventilation was considerable during the winter months in deep mines having a fairly low mine resistance; and under certain conditions, where the temperature was low, natural ventilation would give all the ventilation required without any assistance from mechanical ventilation.

(4) The resistance of the shafts, even if these were of large diameter, formed a large part of the total resistance.

(5) The resistance due to a comparatively small inset might be very large indeed.

(6) The horse-power absorbed by any airway was directly proportional to its resistance for the same quantity.

(7) The increase in total quantity due to natural ventilation was reduced as the water-gauge produced by the fan was increased. The horse-power saved by natural ventilation gradually increased as the total quantity increased.

(8) The observation errors with water-gauge readings, carefully recorded and several readings averaged were, in the experiments described, less than might be expected. At the same time, the use of a more accurate instrument than the ordinary water-gauge was indicated.

(9) In deep mines having a low mine resistance the variation in surface temperature produced a large variation in the total resistance which the fan was required to overcome, and a fan having a good efficiency over a wide range of resistance would give the most economical results.

In the appendix, it was shown that

$Q = \sqrt{Q_n^2 + Q_f^2}$ where Q was the total quantity of air circulating in the mine, and Q_n and Q_f were the quantities circulating in the mine due to the effect of natural ventilation and the fan respectively.

Seymour Wood's Work.

As the question of running mine fans in combinations has been the cause of much discussion, the results of experiments by Mr.E.Seymour Wood, M.Inst. C.E., F.G.S., given in February 1922 in his paper, "Experiments with Single-Inlet, Duplicate and Double-Inlet Capell Fans" before The North of England Institute of Mining and Mechanical Engineers are of interest. After a description of the fan installation and the ventilation scheme, he gave a very full account of his experiments. He made the following deductions:

"(1) Where a fan took the place of furnace ventilation, the water-gauge of the mine being as a rule taken and read underground, in calculating the gauge to be expected from a fan, the resistances due to friction of the downcast and the upcast shafts would need to be included in the calculations.

(2) With two (duplicate) fans working in parallel, the volume of air could be doubled if conditions were favourable, i.e., if the orifice could be increased to allow the volume of air to pass.

(3) With a fixed orifice or fixed mine conditions, with two (duplicate) fans running in parallel, an increased volume of air could be obtained with increased water-gauge, the amount of such additional volume being dependent on the orifice or mine conditions.

(4) Two fans, not necessarily duplicate nor of similar design, running in parallel would produce an increase in the volume of air, provided they were each capable of producing and maintaining the required water-gauge, the increase in volume depending on the size and power of the incoming fan and on the mine conditions.

(5) The results in efficiency showed that a high fan efficiency could be obtained by a fan designed to suit the known conditions of the mine,"

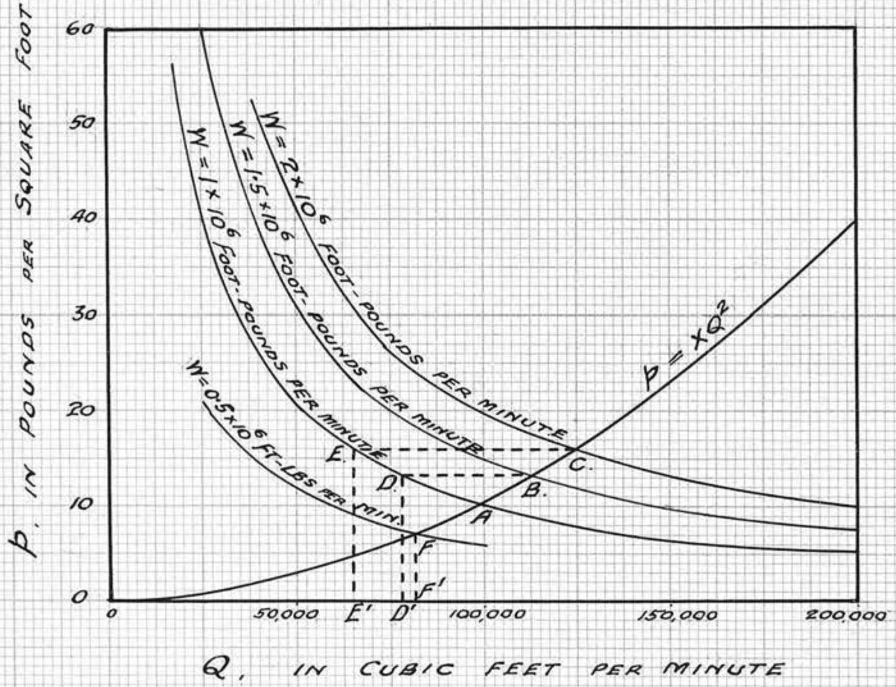


FIGURE 2 — PRESSURE - VOLUME RELATIONS FOR A SINGLE FAN, OR FOR TWO FANS IN PARALLEL AND DEVELOPING $\frac{1}{2}$, 1, $1\frac{1}{2}$ AND 2 TIMES 10^6 FOOT-POUNDS OF USEFUL WORK PER MINUTE

In the discussion which followed, the paper was* severely criticised, Seymour Wood being taken to task for some of his figures even. Attention was also drawn to the low fan efficiency prevailing in this country, and to the need for research along this line.

Parker's Work.

Few people have equalled, far less excelled, the useful work done by Dr.Joseph Parker in Mine Ventilation. He has four excellent papers of recent date, the first of which read in December 1921 dealt with the running of fans in combination. In this paper, "The Operation of Fans in Parallel" read before The Mining Institute of Scotland, Parker pointed out that the authors of previous papers on this subject had considered that the fans, when together, should run at the same speed as when alone, and that under these conditions a large increase in volume would result - in spite of the laws of ventilation. Instead of on constancy of speed, he would focus attention upon constant power. In figure 2, the point A represented the working conditions with one fan running. With two duplicate fans running in parallel and each with the same driving power, the working conditions would be as indicated by the point C, with increased quantity and pressure. The point E would give the conditions under which each fan worked - EE' the pressure and OE' the volume passed by each fan.

If the incoming fan were driven by a machine of only half the power of that of the fan already running, the point B would give the conditions. The point D would give the conditions in the more powerful fan, OD' and DD' representing the volume and pressure respectively. DB would represent the quantity from the incoming fan.

Thus, by the application of fans in parallel with the developed power controlled, the power of ventilating plants could be conveniently varied for less air at week-ends, etc.or for more air as required. Those results would show that power, not speed, should be regulated and that this method was really a practical proposition.

This paper had some adverse criticism which was answered by confirmatory tests carried out by Parker at Wellesley Colliery, Fife, with Waddle and Sirocco fans. A sequel to this last paper and its discussion was given in April 1922 before the same body by Parker; it was entitled "The Characteristic Curves of Fans, and their application to Pre-determine the Output and Efficiency of fans working Singly and in Parallel on Various Resistances." This was a reply to the criticism mentioned, as well as an attempt to find a key to the experimental data already at hand.

Experiments had firmly established that:-

(1) The depression produced by a fan was

proportional to the square of the speed of the fan.

(2) the volume of air delivered by a fan, when working on a mine of constant resistance was proportional to the speed of the fan.

(3) the power required to drive a fan working on a constant external resistance varied as the cube of the volume of air passed per minute, and therefore, also as the cube of the speed of the fan.

(4) the ventilating pressure required to circulate air through a mine was proportional to the resistance of the mine and also to the square of the volume of air circulated.

(5) if a fan were driven at a constant speed on a variable resistance, the water-gauge acting on the external resistance was a fraction of the total or hypothetical depression produced by the fan. The internal resistance of the fan was a function of the square of the volume of air passing through the fan, and the water-gauge available for overcoming the external resistance was the total water-gauge diminished by the water-gauge required to overcome the internal resistance. From those, two other laws could be obtained as corollaries.

(6) the efficiency of a fan working on a mine of constant external resistance was determined by the ratio $\frac{X}{(X+x)}$, and was independent of the speed

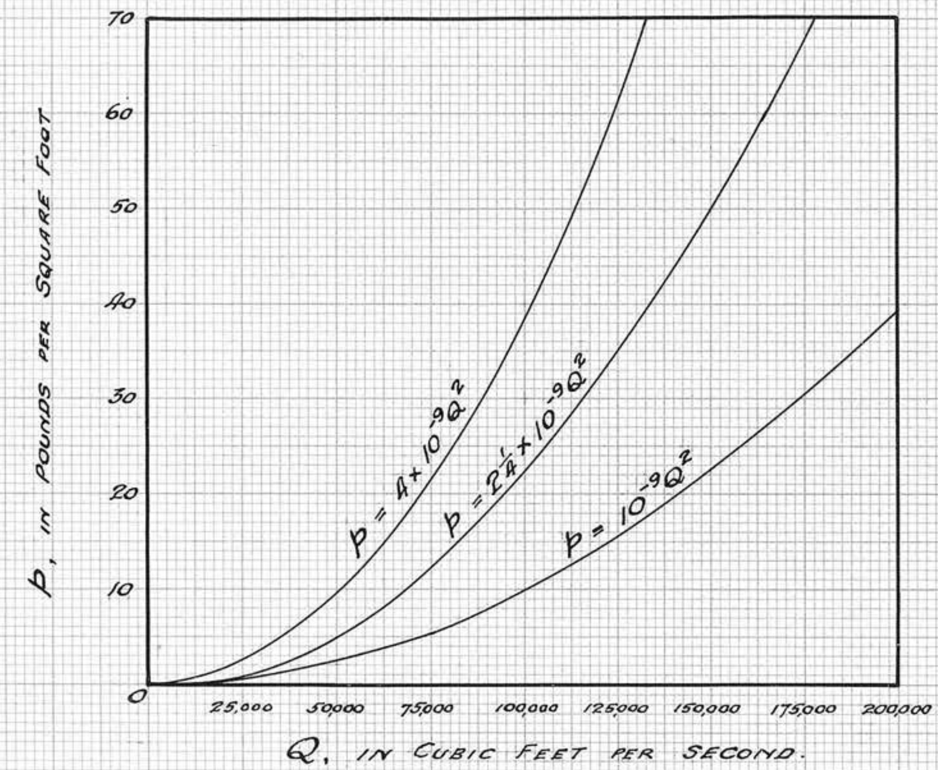


FIGURE 3. — PRESSURE-VOLUME-RESISTANCE GRAPHS.

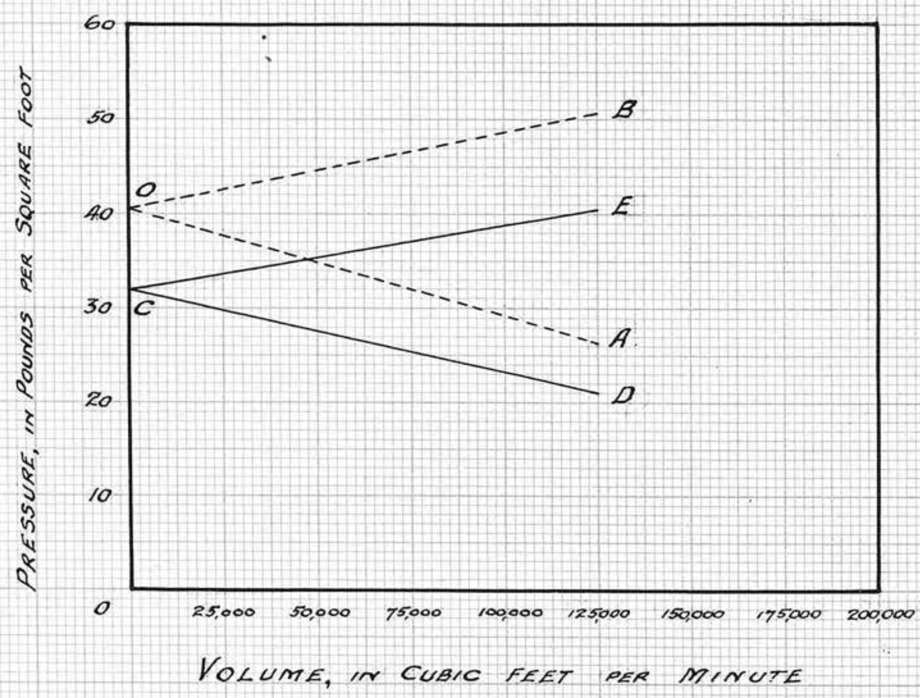


FIGURE 4. — GRAPHS OF THE THEORETICAL AND MAXIMUM VIRTUAL DEPRESSIONS FOR FANS HAVING VANES WITH FORWARD AND BACKWARD CURVATURE RESPECTIVELY.

of the fan. In this ratio, X was the external resistance, and x was the equivalent of the internal resistance of the fan.

7. The equivalent resistance against which fans running in parallel might be considered to operate was equal to 2^2 times the resistance of the mine X, when the fans and motors were duplicate; and for other cases, was n^2, where n was the number of times the two fans were together more powerful than the fan running before being paralleled.

This last would only hold if each fan motor developed the same power after paralleling, as when acting separately. In a duplicate set, if one fan failed to carry its share of the load, the value of n would be reduced below 2. The value of n would be 2, or under, if the more powerful fan were considered as the first running; if vice versa, the value of n would be greater than 2.

Graphs were now required. In figure 3 would be seen graphs equivalent to those which should be drawn through A,D,E in the figure from his previous paper. Figure 3 represented the following laws which we have seen, namely:- No.1, No.4 and No.6.

Hopes of running tests at Wellesley Colliery had not materialised, so theoretical considerations and previous results would have to suffice for this paper.

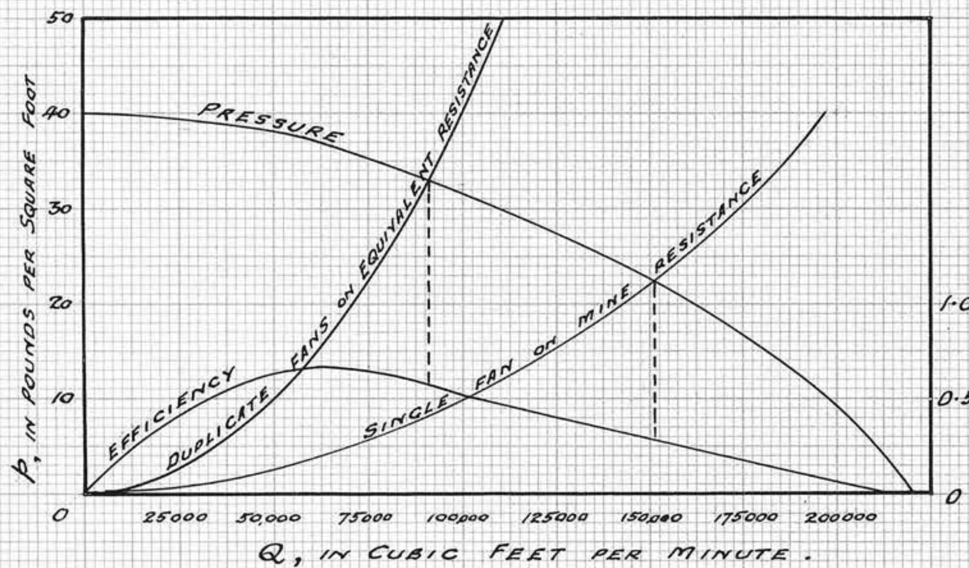


FIGURE 5. – PRESSURE-VOLUME RELATIONS FOR A FAN WITH VANES CURVED BACKWARDS; AND WITH RESISTANCE AND EQUIVALENT-RESISTANCE GRAPHS SUPEP-IMPOSED.

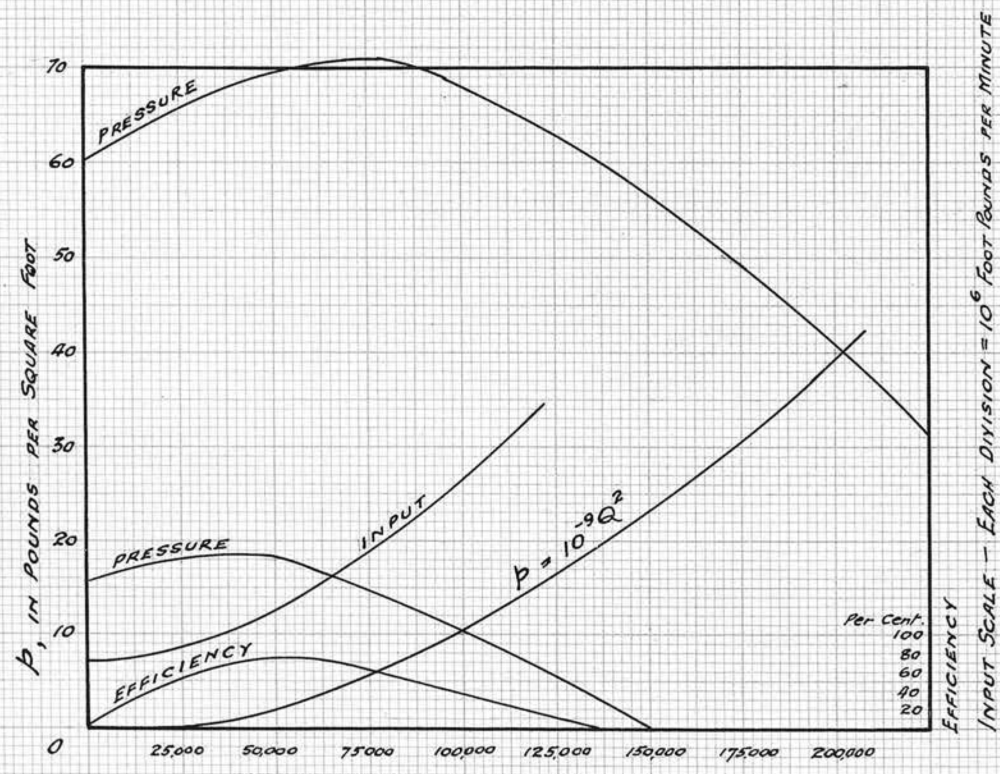


FIGURE 6. – PRESSURE-VOLUME RELATIONS FOR A FAN WITH VANES CURVED FORWARDS; AND WITH RESISTANCE CURVE, INPUT CURVE, AND EFFICIENCY CURVE SUPERIMPOSED.

From consideration of the dynamics of an air particle passing through a fan, and from the well-known formula for the theoretical head produced by a fan, a fan of larger diameter would give a greater depression than a smaller fan for a definite peripheral velocity, and figure 4 could be given - in which OA and OB would give the theoretical motive columns for fans with blades curved backwards or forwards respectively; also, CD and CE would give the corresponding actual depressions.

Figures 5 and 6 would give the pressure-volume relation for fans with vanes curved backward and forward respectively. A useful deduction could be obtained from figure 7. It was seen in the figure that a fan had been working alone at an efficiency of 60 per cent, and when a similar and equally efficient fan, but of one half the motor power was run in parallel with the first fan, the set would operate, as shown, with an efficiency of 70 per cent and would pass more air. Also the motors would be working at a higher efficiency, so a still further increase in quantity would result, if the motors were free to increase in speed to develop their full powers. But, if the incoming fan had been of equal motor power, the efficiency of the set would only be 64 per cent, unless the motors only developed three-quarters of their full power, when 70 per cent would again be reached. This result had, of course, been obtained with a smaller and cheaper set as

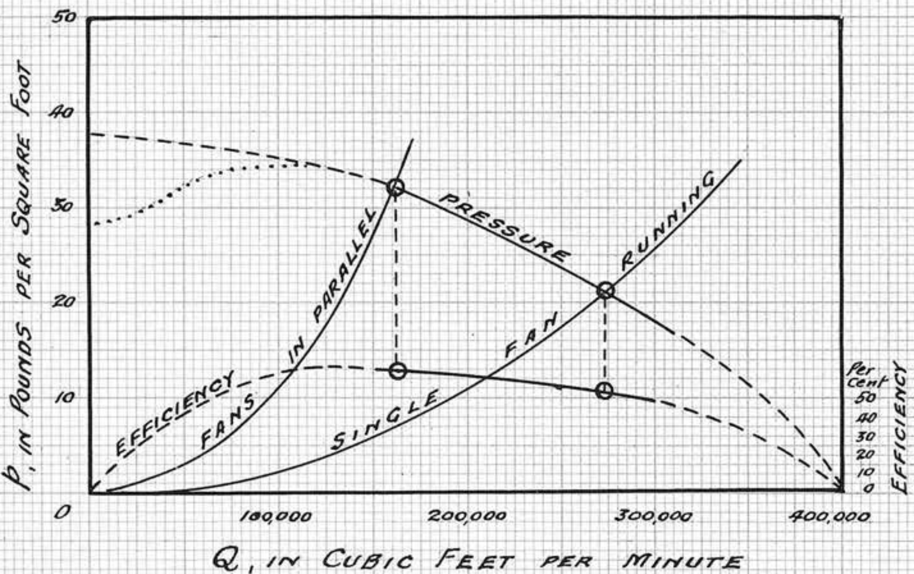


FIGURE 11. – PRESSURE-VOLUME-AND-EFFICIENCY GRAPHS OF MR E. SEYMOUR WOOD'S TESTS AFTER FITTING THE FAN WITH SIXTEEN ADDITIONAL VANES.

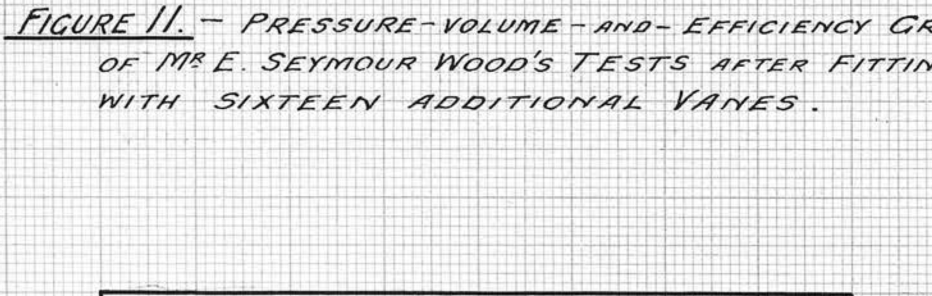


FIGURE 12. – GRAPH SHOWING HOW THE CHARACTERISTIC CURVES OF A FAN MAY BE USED IN THE SELECTION OF A FAN SUITED TO GIVEN REQUIREMENTS.

considered previously. If, however, we considered figure 8, the efficiences corresponding to the above conditions were 40 per cent, 55 per cent, and 65 per cent.

Mr.E.Seymour Wood's results on Capell fans at Murton Colliery, when plotted and utilised as shown in figure 9, would show that the fans would work more efficiently on a mine having a greater resistance. Wood introduced regulators and obtained results as in figure 10, but there would appear to be some doubt about the measured water-gauge of 6 inches for the fans running in parallel, as the water-gauge was calculated to be 8.2 inches, on the assumption that $p \propto Q^2$. To explain this measurement, the required relation would be $p \propto Q^{1.27}$. Probably there had been some accidental source of leakage. Sixteen additional blades were fitted to the fan and results as in figure 11 were obtained - those were in accordance with the relation $p \propto Q^2$. Wood's results also showed that the efficiency of a fan working on a mine of constant resistance was independent of the speed.

The tests required to draw in the characteristic curves of a fan and to predict how it would work under any conditions, and conversely, to choose a fan with the desired characteristics, were to run the fan at a suitable speed, and on a series of resistances varying from 0 to ∞, to determine carefully the input to the fan, the volume of air passed and the depression produced. The pressure-volume and input curves could be plotted; the efficiency curve could be derived. When the resistance graph (and equivalent resistance graph if parallel running was to be considered) had also been drawn, all our questions would be answered. Care would be required in the measurements: the pressure should be measured at a point two-thirds of the distance from the centre to the periphery of the airway.

Although not including himself among the critics of Murgue's equivalent orifice theory, he (Parker) agreed that proper definitions were required in mine ventilation and suggested some for resistance.

By those papers, Parker provided material for a very healthy discussion, to which he replied. By means of figure 12, which he fully explained, he amplified certain parts. To select a fan for a given duty, the pressure-volume and efficiency curves characteristic of the fans offered would have to be obtained from the makers. After deciding upon the efficiency, the proper fan could be selected by his method. He also welcomed Professor Briggs' suggestion of $p = AQ^2 + BQ$ as the equation of the mine characteristic.

An extension of this side of the subject was given in his "Economy and Efficiency in Ventilation" again before the same body in August 1923, when he pointed out that effectiveness of ventilation had been the aim of mining engineers in the past, but that, with the large quantities of air now required, efficiency would have to be considered.

He gave the equation,

$$p_u = \frac{KWV}{g} \left(V - Q\cot\frac{\theta}{60_a}\right) - xQ^2$$

where p_u = useful pressure in pounds per square foot,
K = Murque's "Manometrical Yield",
W = weight of one cubic foot of air,
V = peripheral velocity in feet per second,
g = acceleration due to gravity,
Q = quantity of air passing in cubic feet per minute,
θ = angle between the vanes and the backward extension of the tangent, where the vanes meet the periphery.
a = surface perimeter of the fan in square feet,
and x = internal resistance of the fan.

K and x would be found by experiment, and two sets of relations between p_u and Q would be necessary for the two unknowns. θ, a and V would be found by measurement alone.

The characteristics of a fan could be found by running the fan at a constant speed on two different external resistances, measuring the volume of air passed and the useful ventilating pressure for each case. To smooth out small errors of observation, three measurements of the pressure and volume in each case should be found at a fairly constant speed - the readings would be corrected for any speed variations. The best resistances would be the mine resistance itself and a smaller resistance (by a door left open between the upcast and downcast shafts), or a larger resistance than the mine (by putting in a regulator). An example of this was worked out in full.

In a discussion re regulators in fan drifts, he pointed out that the better scheme would be to instal a variable speed motor, especially if regulation would be required for a considerable time. The results of tests on an 18 inch Sirocco fan were given and showed the ordinary method of obtaining the characteristic curve. The importance of having the correct shape of evasée was mentioned, the maximum angle of divergence being given as 14 degrees; results showing the unequal distribution of air in the evasée of a small fan were also given.

Stand-bye fans were often required at fiery mines in case of accident, and what size to have was an important economic question; and this raised the question as to whether or not the volume of air passing in the mine could be reduced during idle periods. In his opinion, as the working of a mine obstructed ventilation, the volume could quite safely be cut down, when no work was proceeding. Various combinations of fans could be used for this, e.g. series or parallel arrangements, or, for a completely new installation, arrangements of fans of different sizes. By using the characteristic curves of the fans, the correct scheme could be found, a parallel arrangement having a great advantage. There would be an overload on a constant speed motor in the series or parallel arrangements.

As the splits in a mine were seldom found of equal resistances, the choice of a regulator or a booster fan was before the practical man.. Where only a small part of the total volume of air circulated would require to pass through the regulator, or where the necessary drop in pressure at the regulator was small, the regulator would be better than the booster fan. Where, however, in the cases mentioned there was a large volume or a large pressure drop, the booster fan would be preferable. Between those limits, great care in selection would be required. The best position for the regulator was near to where the split to be regulated joined the main return airway; and, generally this was also the best position for the booster fan, which might be either in the intake or in the return airway. Losses in transmission, etc., would be considered with the loss of the regulator from the economic point of view. Wind pressure might in some cases cause an excessive back-pressure on the fan: this could be obviated and the wind pressure made an ally of the fan by having an evasée which automatically turned in the direction in which the wind was blowing. Belt drives would seem to be the most satisfactory, owing to the great fluctuation of load, principally due to two causes - (1) the greatly increased load thrown onto the fan when the cage arrived at the surface, due to greatly increased surface leakage, and (2) the momentarily great drop in the load on the fan at the instant when the cages were passing each other in a shaft with very little clearance space.

Surface leakage was far too great in this country, 50 per cent being by no means an uncommon figure. The gravity of this could be shown symbolically by the following:-

$$Q = Q_m + Q_l = \sqrt{p/X} + p/C$$

where Q_m = volume of air passing through the mine,
Q_l = surface leakage volume,
p = ventilating pressure,
X = mine resistance,
and C = leakage coefficient of the mine.

or

$$Q = A \times \sqrt{W.G.} + B \times W.G.$$

where A and B were constants,
and W.G. = ventilating pressure in inches of water.

In conclusion, he mentioned several types of variable speed alternating current motors for driving fans. American tests on fans driven by variable speed motors indicated, in his view, a very profitable line of enquiry for mining men in this country.

Replying to the somewhat sceptical remarks in the discussion, Parker fully accounted for the points raised.

Another of Parker's papers, namely "The Choice of an Efficient Fan or Ventilator for a Mine" was given in December 1924, before The North of England Institute of Mining and Mechanical Engineers.

He pointed out that the paper was the result of remarks by the President,[1]

[1]"Experiments on the Distribution of Air in Centrifugal Fans, and on Re-entry Phenomena" by Professor Henry Briggs and Dr.J.N.Williamson. Trans.Inst.M.E., 1923-1924 vol.LXVII p.84. in which the latter had pointed out the inefficiency of ventilating plants at mines, due to the variability of the resistance of the mines. This resistance could be split up into components as the resistances of (a) the fan - drift inset, (b) the shafts, (c) the main airways between the shafts and splits, and (d) the splits and workings they ventilate. Neither of these resistances could be large without a serious effective limit being placed upon the volume of air procurable. Often this limit would be placed by the shafts, when those were deep and of small cross-sectional

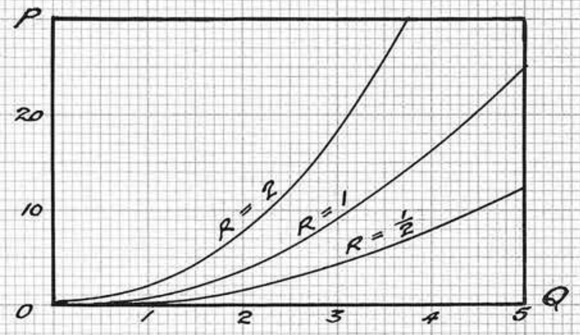


FIGURE 13. – GRAPHS OF RESISTANCES OF $\frac{1}{2}$, 1, AND 2, ATKINSONS.
P IN POUNDS PER SQUARE FOOT.
Q IN THOUSANDS OF CUBIC FEET PER SECOND.

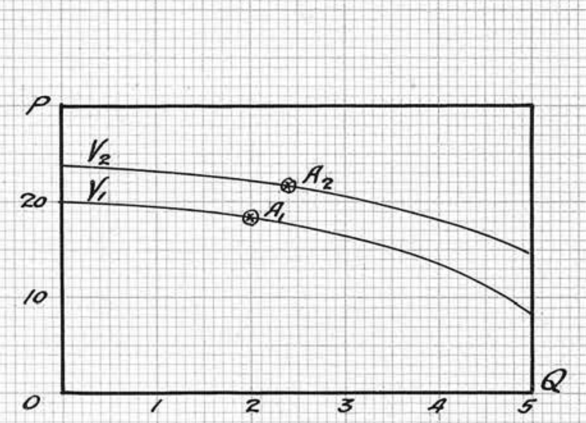


FIGURE 14. – SHOWING PRESSURE-VOLUME CHARACTERISTIC CURVE OF A FAN FOR SPEEDS V_1 AND V_2, AND HOW THE CURVE FOR V_2 MAY BE DERIVED FROM THE CURVE FOR V_1.

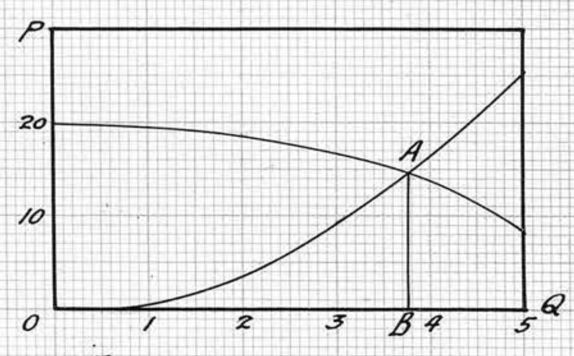


FIGURE 15. – SHOWING A MINE-RESISTANCE CURVE SUPERIMPOSED UPON THE PRESSURE-VOLUME CURVE OF THE FAN.

area, although the effect could be minimised. However resistance in every part should be kept as low as possible. Changes in the resistance could almost be assumed to take place by changes in the mine itself, and this could be kept fairly constant by increasing the number of splits as the mine roadways increased. In a carefully planned ventilation system, the variation of the mine resistance should not fall more than 30 per cent below or rise more than 60 per cent above the normal value. Natural causes also produced effects which would be equivalent to variations in the mine resistance, causing the resistance against which the fan would work to be generally lower. This could be called the "equivalent resistance". In a deep mine, those fluctuations by natural causes had a greater effect than the changes by development of the mine itself. This had been well shown by Mr.Clive[1], when he showed that the resistance of a mine varied from 0.894 Atkinson in summer to 0.393 Atkinson in winter.

[1]Trans.Inst.M.E.1923-24, vol.LXII, p.273.

The resistance of a mine could be shown graphically by a curve, which gave values of P for corresponding values of Q circulated against the resistance R. (see figure 13). The "characteristic pressure-volume curve" for certain speeds would be

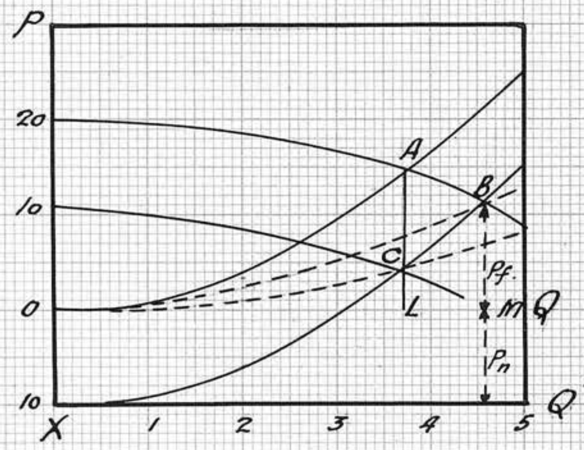


FIGURE 16. – REPRESENTING THE JOINT ACTION OF A FAN AND A NATURAL WATER-GAUGE AND SHOWING HOW THE "EQUIVALENT RESISTANCE" MAY BE DRAWN.

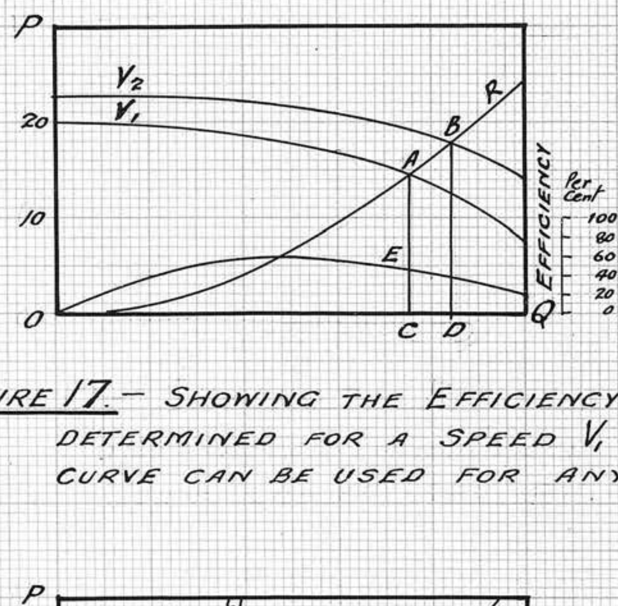


FIGURE 17. – SHOWING THE EFFICIENCY GRAPH OF A FAN DETERMINED FOR A SPEED V_1, AND HOW THIS CURVE CAN BE USED FOR ANY OTHER SPEED V_2

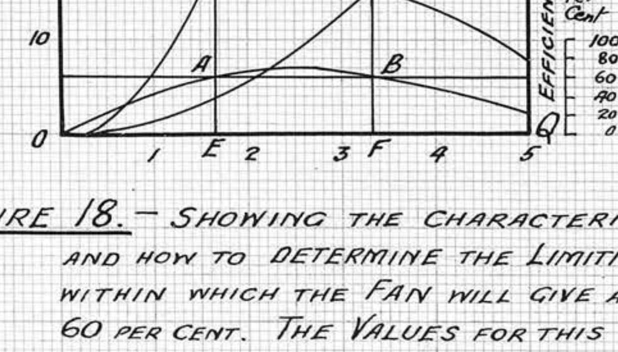


FIGURE 18. – SHOWING THE CHARACTERISTIC CURVES OF A FAN AND HOW TO DETERMINE THE LIMITING VALUES OF THE RESISTANCES WITHIN WHICH THE FAN WILL GIVE AN EFFICIENCY OF NOT LESS THAN 60 PER CENT. THE VALUES FOR THIS CASE SHOW THAT R MUST NOT BE GREATER THAN 7.5 ATKINSONS NOR LESS THAN 1.43 ATKINSONS.

shown as in figure 14. If those curves for a certain case were superimposed one upon the other, they would intersect in one point only, giving the ventilating pressure and the volume of air circulated, when the fan was acting on the given resistance. In figure 15, we would get that the ventilating pressure AB would circulate a volume of air OB against a resistance of one Atkinson. When natural ventilation was present, figure 16 represented the conditions, where P_n gave the natural water-gauge and P_f gave the water-gauge due to the fan. The effect so far as the fan was concerned was the same as if the fan had been set to work on a smaller resistance, represented by the curve OB instead of OA. The "equivalent resistance" value would be given by $\frac{BM}{OM^2}$. An increased quantity of air (from OL to OM) would now be circulated, but as this might be unnecessary, the fan speed could be lowered until the pressure-volume characteristic curve passed through the point C on the mine resistance curve. Then the same amount of air would pass as when there was no natural ventilating effect. The load would now be reduced. The curve OC would give the equivalent resistance against which the fan would operate at the lowered speed.

In the experimental determination of the pressure-volume characteristic, if the fan input and output were also measured and plotted, as in figure 17, a smooth curve could be drawn through those points, giving the efficiency graph of the fan. For a certain speed V_1, the pressure and volume would be determined as shown previously, but, in addition, the efficiency would be given by EC, where this lower curve was the efficiency graph. With an increased speed V_2, the new pressure and volume could again be found, but the efficiency would still be measured by EC, as the efficiency of the fan would be independent of the speed. So, for an altered fan-speed, the efficiency of the fan was given by the intercept corresponding to the pressure-volume curve for which the efficiency curve was determined.

After these considerations, the efficient fan for a definite range of mine resistance could be chosen. Suppose, for example, a fan was required to work with an efficiency of not less than 60 per cent on a mine with a normal resistance; assume also an ordinary variation in the value of the resistance. A fan with the characteristics shown in figure 18 might have been offered. From the figure, it was seen that the 60 per cent efficiency line cut the fan efficiency line at A and B, so giving the range over which the fan would operate as required. The lines EAC and FBD drawn through A and B respectively would cut the pressure-volume curve in C and D. The resistance curves drawn through C and D would give the limiting values of the mine resistance against which the fan would operate with an efficiency of at least 60 per cent. The values of those resistances would be given by $\frac{CE}{OE^2}$ and $\frac{DF}{OF^2}$ respectively. Also, the required conditions would be fulfilled for speeds higher or lower than the speed for which the characteristics were drawn. If the extreme limits of the mine resistance came between those values found, the fan would be suitable; if not, it would be necessary to consider another fan.

The key to the problem of the economic application of fans to mine ventilation was the "equivalent resistance", introduced in his previous paper, "The Characteristic Curves of Fans". In general, the addition of a second ventilating appliance in <u>series</u> with an existing one <u>lowered</u> the "equivalent resistance" against which the latter operated, changing its locus of operation in the characteristic curves, as well as its efficiency. Also, if a <u>parallel</u> combination were used, the "equivalent resistance" would be <u>raised</u>, with the corresponding changes as before. Those two cases were discussed in his two papers, "Economy and Efficiency in Ventilation", and "The Characteristic Curves of Fans". So, by using those combinations, it should be possible to vary the "equivalent resistance" to get an existing fan to work as efficiently as possible. If the fan was not of a good and efficient type, it would be cheaper to scrap it. The fan which would be added to give the proper combination, would be designed to work efficiently at its load.

$$R_e = R\,(n)^2 \quad \text{for fans in parallel}$$

$$R_e = R/_n \quad \text{for fans in series}$$

where R_e was the equivalent resistance, R was the actual mine resistance, and n was the number of times the combined useful output of the two fans was greater than that of the existing fan.

Examples of how to find the required fan for each case were worked out. It was pointed out that in the parallel arrangement, provision should be made to vary the speed of one of the fan-motors so as to distribute the load in the desired proportions; in the series arrangement, no such provision would be required. Another possible solution to the problem of selecting an efficient mine ventilator lay with the application of the air-screw to the ventilation of mines. Mr.F.A.Steart's[1] results were quoted, and the

[1] Journal of The Chemical, Metallurgical and Mining Society of South Africa (1923, Vol.XXIV, p.31)

various advantages of his system ~~were~~ pointed out. The system was very flexible; increased water-gauge would be procured by increasing the number of propellers in series or by increasing the speed: with a fixed number of impellers running at a constant speed, the volume of air passed, could be varied by altering the pitch of the screw : the efficiency of the system was high over a wide range.

As an appendix, a rule for calculating the joint "Admittance" of a number of airways in parallel with each other was given as well as the method of calculating the "Equivalent Resistance" for fans working together on a mine, either in series or parallel arrangement.

Hay's Work.

No mention of mine ventilation, however, brief is complete without some reference to Professor Douglas Hay, whose various papers are always read with interest. In April 1924, he gave a paper,"The Theory of Ventilation; a Review of its Present Treatment, (First Report of The Midland Institute Committee on the Ventilation of Mines)", in which he pointed out that for the last seventy years, the theory of mine ventilation had grown in a very unsatisfactory manner, However, recent work by Penman, Parker etc.had shown the need for more method to express fully work in this subject. The object of this paper was to present a plea for codification of treatment of the subject and to discuss proposed units for the various quantities.

Two assumptions were usually made in discussing the laws of the flow of air in mines, namely:-

(a) That air was an imcompressible fluid within the limits ordinarily met with, and

(b) That the pressure required to produce ventilation varied as the square of the rate of flow.

Those were probably accurate enough to convey a general knowledge of the subject, but assumption (b) required to be more thoroughly investigated. This was easier now as work had been done by Reynolds, Rayleigh, Stanton, Hodgson and Lacey, giving a foundation for similar work in mine galleries. Admitting the assumptions, the two variables, pressure and rate of flow, could be linked together in the form $P = RQ^2$, where R included all the constants. This form was due to Halbaum, although brought more into prominence by Penman and Parker. A more accurate form would be $P = RQ^n$, until assumption (b) had been tested.

There were three objections to the use of the equivalent orifice conception, viz.,

(a) The value of the size of orifice would vary with the density of the air.

(b) The coefficient of the "vena contracta" depended on the nature and size of the orifice.

(c) Since the orifice was proportional to $\dfrac{1}{\sqrt{\text{pressure}}}$, the resulting mathematical treatment became more complicated.

The methods of measuring the quantities thus involved were discussed, the "Atkinson" being suggested as the unit of resistance - that resistance which absorbed one pound pressure per square foot when a volume of one thousand cubic feet per second was passing. Numerical examples of its use were given. Investigation was very much needed, but <u>accurate research</u> was the only kind permissible.

The plea for rationalization of the treatment of ventilation could be summed up under the following heads -

(a) Verification of the law of flow of air,

(b) Standardization of units,

(c) Codification of mathematical treatment, and establishment of basic principles,

(d) Development of better types of instruments and methods of measurements,

(e) Determination of limits of error in observation.

In the very full discussion of this paper, various points were amplified. Several experiences in regard to mine ventilation tests were also given.

A very important contribution to the literature on ventilation was given by Professor Hay and Mr. Clive in June 1924, before the Empire Mining and Metallurgical Congress. In this paper, "The Ventilation of Mines", they pointed out that with the advances in research in general, and with the increase in size of the modern mines, ventilation was a subject which had attracted great attention recently: and the object of their paper was to review and draw attention to modern practice, with its important progress.

The objects of Ventilation were briefly:-

(1) To dilute, render harmless, and carry off noxious gases which were produced in the mine.

(2) In deep mines, to cool the working places, and generally to render atmospheric conditions as to heat and moisture suitable for the conduct of work.

(3) To provide the necessary quantity of fresh air for men and horses to breathe.

(4) To remove the large quantities of dust produced in the working faces by the getting of coal and other minerals.

The importance of (1) and (3) had been appreciated from early times: the true position as regards (2) was beginning to be understood, while (4) was more important than was yet realized.

The metal miner was the first to make use of the methods of ventilation, and in Agricola's "De Re Metallica", in 1556, were found descriptions of appliances to induce the required air currents. Until the middle of last century very little alteration had been made in the devices used. Since then, however, various appliances had been put to use, and then discarded in favour of the modern centrifugal fan.

Unfortunately the principles of the

ventilation of mines had been dealt with as two separate subjects, - one dealing with the circulation of the air in the mine, and the other pertaining to the machines themselves. The two problems were really one. In 1862, ten years before Murgue expounded his equivalent orifice theory, Atkinson, in his well-known paper, "General Principles of Ventilation" pointed out that various hydraulic formulae could be applied to air-flow in mines. This gave a foundation for mathematical theory in Mine Ventilation. Those formulae mentioned were based on the hypothesis that the resistance to the flow of a fluid in a duct was -
(a) Independent of the pressure in the duct, and (b) Proportional to the "rubbing" surface, to the density of the fluid and to the square of the mean velocity. Atkinson expressed this relation in the form

$P = \frac{K\,s\,v^2}{a}$, where P was the pressure overcoming the resistance for a given velocity of flow v,

s was the "rubbing" surface,

and a was the area of the duct.

In its present form, the general problem was very difficult, and simplification was required. This could be obtained by turning Atkinson's formula into another form -

$P = R\,Q^2$, where Q = rate of flow = a v

and $R = K\,\frac{s}{a^3}$.

In this type, R included all the constants, and, therefore, was the specific resistance of the airway referred to a standard air density. All should be in foot - pound - second units. This last formula applied equally to fan and airways problems.

As mines increased in size, this resistance increased, and to obtain better ventilation, the total resistance to air-flow was reduced by conducting the air in a series of parallel courses. This was suggested by Atkinson, and was called "splitting the air". In general, if a mine was ventilated by n splits of equal resistance, the power required in series equalled n^3 power required in parallel. The ideal arrangement was as below:-

(a) The mine should be divided into districts or parts of approximately equal resistance, each ventilated by a separate current or split of air.

(b) All these air-currents should be arranged in parallel, the point of splitting to be as near the shafts or outlets as possible.

(c) The number of splits should not be too small, otherwise there would be an excessive length of face ventilated by each air current. Moreover, the mine resistance as a whole would be unduly increased.

(d) On the other hand, too many splits would result in the air velocity in the faces being reduced too much.

The ideal condition that all splits should be of equal resistance was not always achieved in practice, and it became necessary to -

(a) Regulate one or more splits, or

(b) Boost up the pressure in the other splits by auxiliary fans.

The general principles for the efficient ventilation of the faces, headings, etc., were well known, and did not need mention in the paper. Two important factors required attention - (a) the influence of leakage and (b) the influence of the size of the airway. As regards this first factor, insufficient attention was paid to leakage through doors, stoppings, etc., and especially when underground fans were used, as local circulations of impure air might be produced. The loss of power entailed by small airways was seldom realized. We had Power $\propto$ Resistance $\propto \frac{s}{a^3}$, from which, for an airway of circular section, of diameter d, we found Power $\propto \frac{1}{d^5}$. Therefore, airways should be of as large a cross-section as possible, consistent with the strength of the strata.

Of the modes of production of ventilation, the method due to natural causes was the most irregular. Natural ventilation was due to the difference between the weight of air in the upcast and downcast shafts and inclines, and upon the resistance of the mine. Its effect used to be enlarged by furnaces, but this method was now superseded by mechanically driven fans, which were generally at the surface. In a few cases in metal mines and in coal mines working several separate seams, the fans might be placed underground, e.g., Hulton Colliery, Lancashire. In this latter scheme, the disadvantages of the fan being below ground overcame the advantages gained. Fans might also be installed underground as auxiliary fans, e.g.to obviate excessive use of regulators, to regulate the difference of ventilating pressure between intakes and returns and so avoid excessive leakage.

In all mines the effect of natural ventilation was a varying one. In older mines the effect was quite small, whereas in modern deep mines, it was quite appreciable. It might enlarge or reduce the effect of the fans, and those machines had to work on a varying resistance. In "The True Effect of Natural Ventilation in Deep Mines"[1] by Mr.R.Clive, it was shown

[1]Trans.Inst.M.E.1923-1924, Vol.LXVII, p.273

that in one particular case, the horse-power in the air required to be dealt with by the fan varied from 182 H.P. in summer to 80 H.P.in winter.

To ventilate headings, pipes were often used. Those should really be in conjunction with a small fan; if not, it was better to use a "brick brattice" about two feet from one side of the roadway, provided there was enough space. With the pipes, centrifugal fans could be used, as well as Compressed Air Blowers, e.g. of the Venturi pattern, and the Koerting Jet Ventilator. At La Peronnière Colliery, in France, there was a good example of modern effort in this line. To ventilate a heading 1,000 metres long, a Rateau fan was made to pass 2,000 cubic feet of air per minute at a pressure of 30 inches of water through sheet iron pipes (14 inches in diameter).

The small multi-vane type of fan was much in favour to-day, but most of the older types had been brought up to date. Indeed, any fan of a reputed make would give excellent results, but efficiency in ventilating plants required that the fan-inlet and evasée, as well as the fan itself, should be well designed. Also, even more important was the selection of a fan of a suitable size. The ratio $\frac{\text{mine resistance}}{\text{fan resistance}}$ should have a definite value, varying but little for different types of fans. This quantity was independent of the volume of air passed or of the speed of the fan. The mine resistance varied to some extent, so many fans were working under very unfavourable conditions. Fans might also be operated in parellel or in series. Penman[1] and Parker[2] had gone into this question very thoroughly.

[2] Trans. Inst.M.E.1921-1922, vol.LXIII, p.222.
[1] Trans. Inst.M.E.1921-1922, vol.LXII, p.39.

The use of Ventilation in deep mines had been pointed out. This increase in the wet and dry bulb temperatures in the air in the workings was due to -

(1) Heat due to compression as the air descended the shaft,

(2) Heat due to conduction from the surrounding strata,

(3) Heat due to the oxidation of coal and other minerals,

(4) Heat and moisture given off by men, horses, lamps, underground engines, etc., and

(5) Moisture picked up by the air in wet mines, and from newly uncovered strata such as coal.

Those factors varied in importance in different cases, but in general the best cure for their effect seemed to be increased and systematic ventilation, preferably with a low water-gauge. Only exceptionally would other means be required.

As the ventilation of modern mines consumed a large amount of power, the efficient circulation of air in the underground roadways assumed economic importance. To save power, regard had to be paid to efficient "splitting", roadways of adequate cross-section, leakage, etc. The system would need to take into consideration the future development of the mine. Each type of mine required separate consideration, but two extreme cases would be briefly dealt with:-

(1) The horizontal coal seam, and

(2) The steeply inclined metal vein.

(1) Two schemes were required, namely:-

(a) The permanent scheme to operate when the pit was developed, and

(b) A temporary system which would operate during the opening out and development, and until the permanent system was available.

Various notes on this subject were given, and the arrangements at Bentley Colliery, Yorkshire, were shown.

(2) Natural ventilation often sufficed in metal mines, but, at some stage in the life of the mine, artificial ventilation would probably be required. There were two cases:-

(a) Where all shafts were in the vein, and effective sealing of one or more was difficult; and

(b) Where at least one shaft was driven vertically with cross-cuts at the different levels, which could be easily sealed off.

In case (a), leakage was a big factor, and case (b) presented more favourable conditions. There was a tendency to sink large vertical shafts for opening up lower levels, and for the improvement of the ventilation system. This was illustrated by the case of the Tresavean Mine, Cornwall.

As a review of existing conditions, a table gave twenty-eight examples of ventilation systems in coal mines in this country.

With the development of mines, new schemes of ventilation were required. There was a call for research. A question often raised in this respect was as to how far the laws of flow of air, which were assumed in the treatment of the subject, were valid; and, if not, how far any departure from them might be of practical interest and value. Modern views originated with Osborne Reynolds in 1883, when the following expression was given:-

$$\frac{V_c\,dp}{\mu} = \text{constant, where } V_c = \text{critical velocity,}$$

d = diameter of pipe,

p = density of fluid,

and μ = viscosity.

At speeds above the critical, the law of resistance to flow would be given by an equation of the form $R = Cv^n$. This was only an approximation, but over a limited range, its accuracy was fairly high. In 1909, Lord Rayleigh showed that the general law of the flow of fluids moving in ducts of similar character but of different linear dimensions, was given by:-

$$R = Pv^2 f\left(\frac{vdp}{\mu}\right)$$ where f was a function of one variable $\left(\frac{vdp}{\mu}\right)$

This was verified by Stanton and Pannel with experiments carried out from 1910 to 1915. The importance of the relation lay in the fact that the coefficient of friction in the Chezy and similar hydraulic formulae could be shown to be $K = \frac{R}{\frac{1}{2}pv^2}$. It therefore followed

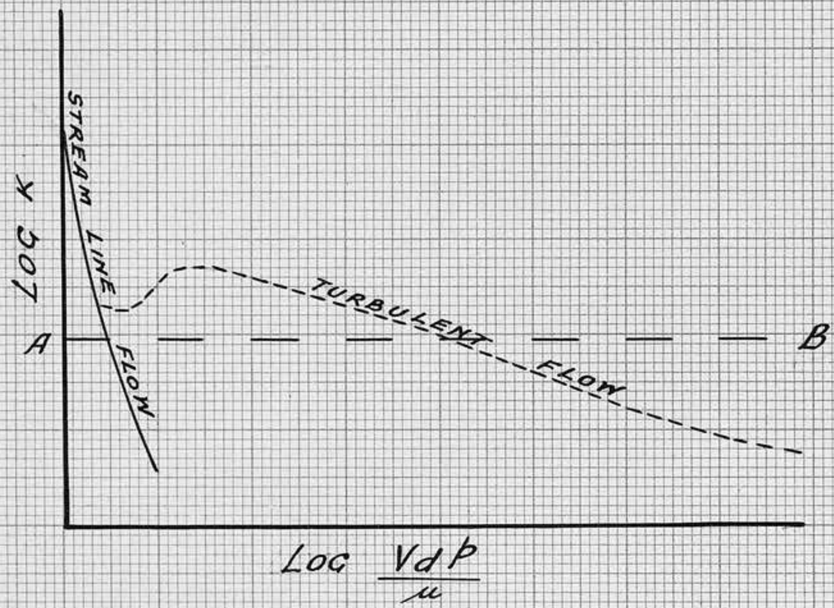


FIGURE 19. – DIAGRAM SHOWING VARIATION IN COEFFICIENT OF FRICTION.

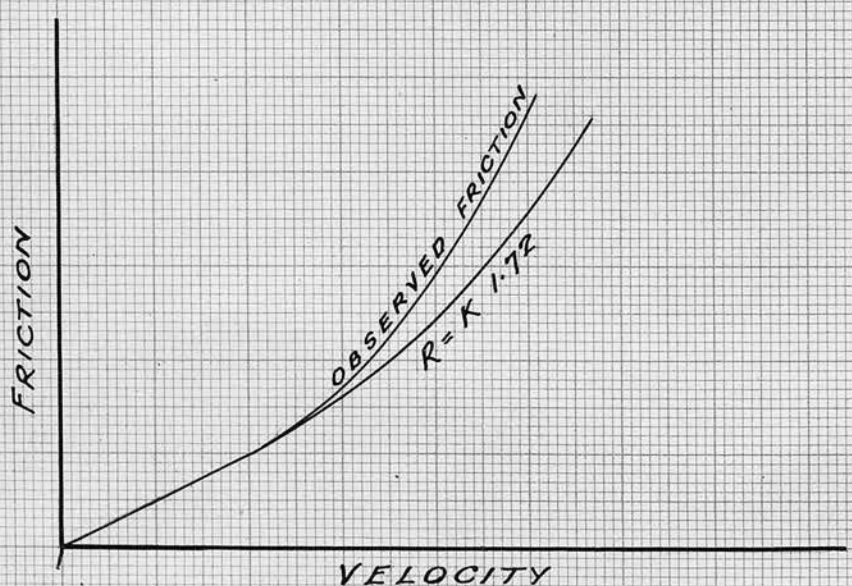


FIGURE 20. – DIAGRAM SHOWING VERIFICATION OF INDEX LAW OF RESISTANCE.

that if, for a particular duct and a particular fluid, the relation between $\frac{R}{\frac{1}{2}\,pv^2}$ and $\frac{vdp}{\mu}$ was found experimentally, the value of K could be declared for any fluid of known density and viscosity, flowing in a duct of any linear dimension and at any velocity, if the value of $\frac{vdp}{\mu}$ for the particular conditions of flow lay within the range for which values of K had been previously determined. Figure 19 showed the graphical relation between $K \equiv \frac{R}{\frac{1}{2}pv^2}$ and $\frac{vdp}{\mu}$, as given by Stanton.

As shown in figure 20, Stanton had also tested the law $R = C\, v^n$ for a pipe 1.255 cms.in diameter, using water up to a rate of flow of 3,000 cms.per second. The values of n varied in those results from 1.72 to 1.92. The index law was therefore only approximate. Lacey had done work on the flow of gas in small pipes up to two inches diameter. Hope was expressed that similar work could be undertaken for the flow of air in mine galleries.

Accurate instruments were required for research work in ventilation. Wind-vane anemometers and simple U tube water-gauges were not good enough, even for routine work. Recording instruments would improve ventilation systems, if their limits of accuracy were known and recognised.

Hope was expressed that in the near future the whole subject of ventilation would be made much clearer, to everyone's advantage.

As the paper was really a review, there was practically no discussion, the remarks being of a very congratulatory nature. However, many emphasized the advantages of keeping mine resistance as low as possible. Professor Douglas Hay was also joint author, with Mr.W.E.Cooke, of a paper, "A Review of Hygrometry in Mining Practice (Third Report of the Midland Institute Committee on the Ventilation of Mines)", given before The Midland Institute of Mining Engineers in November, 1925. It was pointed out by the authors that a knowledge of the humidity and temperature of a mine atmosphere was of importance in several directions, the principal of which might be stated as under:-

(1) The determination of the physiological effect of the air on the mine personnel.

(2) The fact that humidity and temperature records might give valuable indications of the occurrence of spontaneous combustion.

(3) The determination of air-density from observations of temperature and humidity.

The various types of hygrometers and the tables to be used in conjunction with them would be discussed. There were four general types of hygrometers:-

(a) Wet- and dry-bulb hygrometers.
(b) The dew-point hygrometer.
(c) The hair hygrometer.
(d) The absorption type of hygrometer.

(a) This type required a current of air, exceeding a certain velocity, to pass the bulbs - either by drawing air by a fan or by whirling the hygrometer.

(b) This was a more accurate type than (a), but was more for laboratory than mine work.

(c) The hair hygrometer required frequent calibration, but was of considerable utility, in low temperatures. A continuous record could be obtained with this type.

(d) A skilled operator was required for this last type, and, as some time was required to make an observation, it did not seem suitable for use in mines.

Some instruments of those types were described.

For ordinary mining work, the whirling hygrometer should be used.

After discussing the theory of the Wet-and Dry-bulb Hygrometer, Psychrometrical Tables were described. For mining purposes, those tables should give the following information, corresponding to various readings of the wet-and dry-bulb thermometers and of the barometer:-

(a) Relative humidity.
(b) Density of air in any degree of saturation.
(c) Weight of water present per unit weight or volume of dry air (or of the mixture).

It was also useful to obtain:-

(d) Dew-point.
(e) Vapour-pressure.

Those tables should also, for mining work, cover a temperature range of from 130° down to 32° Fahr.or lower, and a barometric range of from 27 to 33 inches of mercury.

The principal existing tables were:-

(A) Jelinek's tables.
(B) Meteorolical Office tables.
(C) Marvin's tables.
(D) Jones' tables.
(E) Psychrometer tables of the Prussian Meteorological Institute.
(F) Glaisher's tables.

Jelinek's, the Prussian Meteorological Institute's and Glaisher's tables were unsuitable for our use in mining work, while the Meteorological Office tables were unsuited for deep mines. Marvin's tables were also inconvenient as they did not give tables for obtaining density. Jones' tables were designed for mining work and seemed fairly suitable. All the tables would give reliable information, nevertheless, although perhaps not as easily as was possible. Jones' tables seemed the best at present available, but some competent body should be appointed to standardise tables and instruments for mining use.

Before the same body, Professor Douglas Hay and Mr.W.E.Cooke, gave another paper, "Underground Tests on the Flow of Air at Rockingham Colliery. (Fourth Report of The Midland Institute Committee on the Ventilation of Mines)" in March 1926.

After describing at length the apparatus used

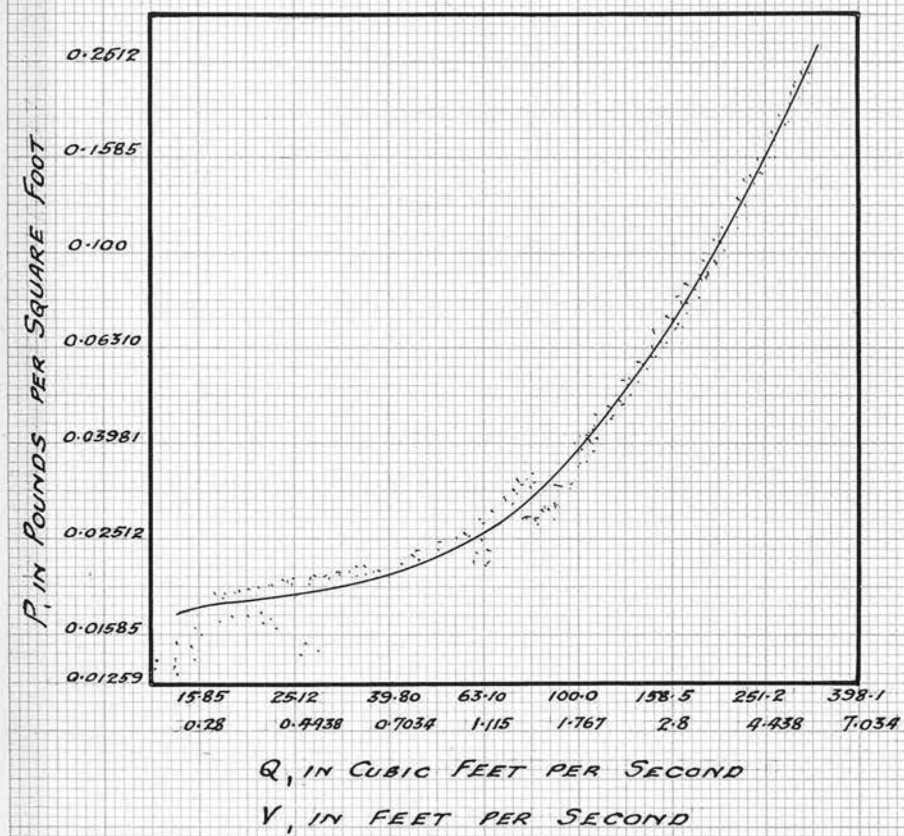


FIGURE 21. – VELOCITY AND LOSS OF PRESSURE OBSERVATIONS.

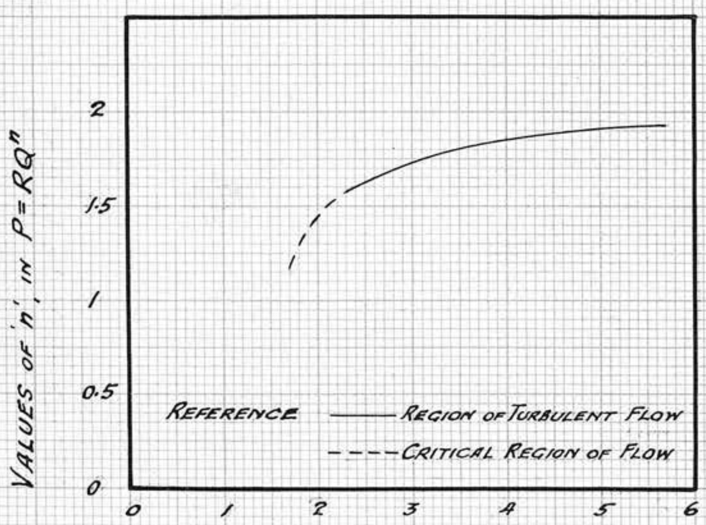


FIGURE 22. – VARIATION OF INDEX WITH RATE OF FLOW.

and the general method followed in the experiments, the results of 700 observations of loss of pressure and rate of flow of air were given, as in Figure 21. The mean curve was as shown although it was not known what weight it would carry. A region of instability was shown between velocities of 0.25 feet per second and 2 feet per second, probably due to the fact that the air-flow was "mixed" - neither stream-line nor turbulent. Above a velocity of 2 feet per second, the flow was turbulent and steady.

Values of the index in a simple index law were found, as shown in Figure 22.

The following summary was given:-

(1) The experiments covered a limited range of air - velocities in a typical main airway at a colliery.

(2) At moderate air-velocities ranging between 4 and 6 feet per second, definite values of resistance were obtained, the index applicable to the index law, $P = RQ^n$, increasing from 1.6 to 1.9.

(3) It was possible that at velocities higher than 6 feet per second the square law would obtain, but further work was in progress to test this point.

(4) The experiments at air speeds below 2 feet per second required further confirmation.

(5) The value of the Atkinson coefficient for the airway was approximately 0.00214 at velocities over 4.5 feet per second. Below this velocity, the

coefficient was not even approximately constant, but rapidly increased.

(6) Similarily, the resistance of the airway might be stated in Atkinsons. In the present experiments, the resistance of a standard length of 1000 feet was approximately 6.8 Atkinsons.

In an appendix, the construction of the manometer used, a table of values of the coefficient of friction, and a demonstration of Bernouilli's Theorem applied to the case of an exhausting fan were given.

In the discussion, various points were raised, most attention being paid to the manometer.

Cooper's Work.

Before The Mining Institute of Scotland in October 1921, Mr.James Cooper read a paper, "The Testing of Anemometers". He pointed out that the two best known methods of measuring air velocities in mines, vix.by the anemometer and by means of smoke, were both liable to serious error. As the anemometer was the only one of those two, which was of any practical value, it was decided to test this type of instrument. Frequent tests were necessary, especially for low speeds. For those experiments a "table" similar to that of J.J.Atkinson and J.Dalgleish[1], and

[1]"The Velocities of Currents of Air in Mines" Trans.N.E.Inst. 1861-1862, vol.X, p.207.

designed by Professor Henry Briggs had been used. This instrument was described.

The first series of tests was carried out to discover what influence, if any, would result by fixing the anemometer on the arm of the "table" at different radii, which varied from $6\frac{1}{2}$ feet to 1 foot. A 6 inch and a $2\frac{3}{4}$ inch anemometer were used giving similar results. The results obtained at the larger radii were fairly consistent with straight-line walking tests. The correct chart for the greatest radius crossed the zero-line at a greater velocity than the other curves, but for velocities between 500 feet per minute and 2,000 feet per minute, the latter being the maximum achieved, the correction at all radii was approximately the same. 6 inch, 4 inch and $2\frac{3}{4}$ inch anemometers, all of which were in regular use, were tested at a radius of 5 feet 5 inches. Speeds of 50 feet per minute to over 2,000 feet per minute were recorded. At the low rate, only the 4 inch anemometer (a new instrument) and the 6 inch anemometer (recently overhauled) gave consistent results; the others gave unreliable readings which required large corrections. For velocities from 500 feet per minute up to over 2,000 feet per minute, the corrections for all the instruments were fairly uniform.

Measurements of velocity by the anemometers and by means of smoke were made, and proved how unreliable the latter method was.

Walking tests were made to calibrate the anemometers by walking in still air with the instruments. Each instrument was used in turn and held in the hand, while the experimenter travelled a straight path of 66 feet in times varying from 5 seconds to 40 seconds. The results so obtained were fairly similar to those obtained before, thus proving that for all practical purposes this simple method was good enough.

In conclusion, the unsuitability of the anemometer for measuring low air velocities was emphasised; and, be it noted, this was the duty for which the anemometer was really required in mine work.

In the discussion of this paper, the need for frequent calibration of anemometers was emphasised, but the condemnation of the smoke test was questioned.

Table I.—Particulars of Collieries at which the Tests were Carried out.

No.	Name and situation of mine.	Ventilating system.					Particulars of seams.				Particulars of shafts.		Approximate weekly output.	Further remarks
		Type of fan.	Dimensions of fan.	No. of auxiliary fans	Connexions to other mines.	Number of main splits	Name.	Height.	Average inclination.	Method of working.	Downcast.	Upcast.		
								Ft Ins					Tons.	
1	Arniston (Midlothian)	Sirocco (double inlet)	Diameter, 77 inches; width, 63 inches.	2	None	8	Great Seam .... Diamond .... Blackbird .... Coronation .... Splint .... Kailblades' .... Little Splint....	6 3 1 11 2 6 2 0 4 0 4 0 2 0	1 in $2\frac{1}{2}$ to 1 in 5	Longwall (machine and hand)	(1) 960 feet deep; 15×9 feet, timber lining (slightly wet). (2) 960 feet deep; $17\frac{1}{2}\times9\frac{1}{2}$ feet, timber lining (dry).	600 feet deep; 8 feet in diameter; rock sides (wet).	7,000	Old colliery, having extensive workings.
2	Easthouses (Midlothian)	Sirocco (propeller)	Diameter, 70 inches; 5 blades.	1	To Newbattle; also to old workings		Great Seam	6 0	1 in $2\frac{1}{2}$	Bord-and-pillar	Incline from surface, 4,740 feet long; gradient, 1 in $2\frac{1}{2}$.	Incline from surface, 4,800 feet long; gradient, 1 in $2\frac{1}{2}$.	1,500	Connexions to Newbattle closed during tests.
3	Polkemmet (Linlithgowshire)	Sirocco (double inlet)	Diameter, 105 inches; width, 84 inches.	None	None	4	Wilsontown Main Coal	4 0	1 in 20	Longwall	1,572 feet deep; 20 feet in diameter; brick lining.	1,572 feet deep; 20 feet in diameter; brick lining.	7,000	—
4	Prestonlinks (Haddingtonshire)	Howden (double inlet)	Diameter, 13 feet; width, 81 inches.	3	None	4	Great Seam .... Jewel	3 0 3 0	1 in 8 to level	Longwall	400 feet deep; $22\times10\frac{1}{2}$ feet, timber lining (slightly wet).	400 feet deep; 17 feet in diameter; brick lining (slightly wet).	6,000	Extensive workings.
5	Dunnikier (Fife)	Waddle	Diameter, $26\frac{1}{2}$ feet.	None	To old workings	3	Jersey .... Lochgelly Splint .... Parrot .... Five Foot	2 0 2 11 2 0 3 4	1 in 4	Longwall	701 feet deep; 16×7 feet, timber and rock sides (very wet).	701 feet deep; $13\frac{1}{2}\times9\frac{1}{2}$ feet; timber lining (slightly wet).	1,800	Old colliery, having extensive workings.
6	Kinglassie (Fife)	Walker (double inlet)	Diameter, 18 feet; width, 7 feet	None	None	2	Dunfermline Splint Lochgelly Splint	3 3 to 3 6 2 3 to 3 0	1 in 18	Longwall	1,050 feet deep; $20\times11\frac{1}{2}$ feet, timber and brick lining (wet).	1,040 feet deep; $14\times11\frac{1}{2}$ feet; timber and brick lining (slightly wet).	3,000	—
7	Valleyfield (Fife)	Walker (double inlet)	Diameter, 18 feet; width, 7 feet.	None	None	7	Jewel .... Diamond .... Five Foot .... Dunfermline Splint	4 6 4 3 6 0 3 0	1 in 3	Longwall	1,150 feet deep (elliptical); brick lining (dry).	1,160 feet deep (elliptical); brick lining (dry).	4,300	—
8	Wellesley (Fife)	Waddle Sirocco (double inlet)	Diameter, 21 feet; width, 21 inches. Diameter, 119 inches; width, 7 feet.	4	To several mines	5	Barncraig .... Chemiss .... Bowhouse .... Dysart Main....	4 6 7 0 3 0 8 0	1 in 6	Longwall	1,554 feet deep; $27\frac{1}{2}$ feet × 14 feet 10 inches (elliptical); brick lining (dry); 8 ~~20~~-inch steam-pipe; 6 ~~18~~-inch steam-pipe.	1,513 feet deep; top 900 feet, 17×9 feet; bottom 613 feet, same as downcast.	10,500	—
9	Hylton (Co. Durham)	Sirocco (double inlet)	Diameter, 91 inches; width, 63 inches.	2	None	13	Maudlin .... Hutton .... Harvey	5 6 4 6 2 8	1 in 20 to 1 in 30	Bord-and-pillar. Do. Longwall	(1) 1,439 feet deep; (2) 1,758 feet deep; both shafts 20 feet in diameter; brick lining (dry).	1,761 feet deep; 15 feet in diameter; brick lining.	8,500	—
10	Silksworth (Co. Durham)	Capell (double inlet)	Diameter, 12 feet; width, 6 feet.	None	None	15	Five-Quarter Maudlin .... Hutton	3 0 5 6 4 0	1 in 18	Longwall	1,741 feet deep; $16\frac{3}{4}$ feet in diameter; brick lining.	1,741 feet deep; 14 feet in diameter; brick lining.	14,000	—
11	Coventry (Warwickshire)	Sirocco (single inlet)	Diameter, 175 inches; width, 58 inches.	None	None	5	Thick Coal, consisting of Two Yards Bare Coal .... Ryder Ell Coal Slate Coal	 4 0 1 3 6 6 6 6	1 in 10	Modified longwall retreating.	2,121 feet deep; 21 feet in diameter; brick, tubbing, and concrete lining (semi-dry).	2,138 feet deep, otherwise same as downcast.	11,000	—
12	Craven (Warwickshire)	Sirocco (double inlet)	Diameter, 49 inches; width, 45 inches.	None	None	3	Slate Coal	Do.	1 in $1\frac{1}{4}$	Do.	255 feet deep; 9 feet in diameter; brick lining (dry).	195 feet deep; 8 feet in diameter; brick lining (dry).	3,000	—

PART II.

EXPERIMENTS ON MINE VENTILATING SYSTEMS.

After consideration of the recent papers reviewed in the last section, it will be realized how much doubt there was as regards the relation $P \propto Q^2$. This and the importance of the connexion between the air-volume and the fan-drift pressure instigated the research to be described. The objects of the work were:-

(1) To study the relationship of air-quantity and fan-drift pressure, and to test the relation $p \propto Q^2$.

(2) To study the relationship of air-quantity and fan-speed, and to test the relation $Q \propto S$.

(3) To study the relationship of fan-drift pressure and fan-speed, and to test the relation $P \propto S^2$.

(4) To find the internal resistances of mine fans when stationary.

(5) To study natural ventilation and its measurement.

Particulars of the Mines. Table I. gives a number of particulars of the mines at which the experiments were carried out. The endeavour was to run the tests on pits which might be considered representative of British collieries. Of the twelve, eight are in Scotland and four are in England. Of the Scottish pits, four are in the Lothians and four are in Fife:

two of the English mines are in County Durham and two are in Warwickshire. The collieries are at various stages of development. Polkemmet Colliery is a new winning (shafts completed in 1924): Coventry Colliery (shafts completed in 1917) is just reaching full output and many of the others have been full-grown for some time. Craven Colliery is an example of a pit in old age, while at Dunnikier Colliery work has been stopped in the seams being worked when the tests were made. There is one example (Easthouses Colliery) of a colliery working the coal seams by means of inclines from the surface: all the others have vertical-shafts, two of this number having each a pair of downcasts and one upcast. In certain cases, especially in Scotland, the pits are connected to adjacent collieries, while Dunnikier Colliery and Easthouses Colliery are joined to old workings. This is a disadvantage as independent ventilating systems are to be preferred for the tests. In this respect, there is less difficulty in England than in Scotland. Underground fans are installed in several cases. As the tests were carried out at week-ends and holidays, it was found possible to stop these auxiliary fans during the tests, with the exception of two at Prestonlinks Colliery, which had to continue running, except for the short periods when the main surface fan was stopped.

As one might expect from the geographical distribution of the pits, there is considerable variation in regard to the thickness and the inclination of the seams wrought at those mines, the former ranging from 1 foot 11 inches to 18 feet 3 inches, and the latter from 38° to level. Depending upon this variation, the methods of working differ also, both in respect of system and the use of coal-cutting machinery. There is also variety in the method of lighting in the pits, about half of which use naked lights, and the other half safety lamps. Three of the mines have steam-pipes in the shafts. In two, viz., No.6 and No.8 (see Table 1.) those are in the downcast shaft, while in No.3, the pipe is in the upcast.

All the surface fans are of the suction or exhausting type. Seven are Siroccos of diameters varying from 4 feet 1 inch to 14 feet 7 inches; four are of types with blades bent backwards at the periphery of the wheel, and range from 13 feet to 26½ feet in diameter, while the other is a five-bladed propeller 5 feet 10 inches in diameter. In a preliminary inspection all those were found to possess suitable facilities for the carrying out of the tests and the taking of the measurements required.

Three tests were intended at each of the twelve mines, in order to get results corresponding to summer, spring and winter conditions. Unfortunately, owing to the recent stoppage in the coal industry, it was not possible to complete this programme.

Method of Conducting the Tests. In carrying out the experiments, five observers, as well as guides, occasional helpers, etc., were required. The first observer was entrusted with the water-gauge observations, the second with the reading of the fan speed, the third with the measurement of the air-velocity with the help of the fourth as time-keeper, and the fifth with the recording of the barometric and hygrometric conditions underground. The second observer was responsible for altering the speed as required, and the third also took readings of the barometer and hygrometer inside and outside the fan-drift. The aneroid barometers and the hygrometers were calibrated against standards in the laboratory, or compared, previous to use at the pit, with instruments which had been so calibrated. The whirling type of hygrometer was used, and the desired data were obtained by reference to Marvin's Tables[1] (see Hay's work).

[1] Smithsonian Meteorological Tables, Washington, U.S.A 1893.

When the instruments had been tested and made ready for use, all watches were synchronised and the person entrusted with the observation of the underground hygrometric and barometric conditions proceeded down the pit. There he generally remained until the end of the period of test. The necessary observations were then made at the first speed, usually the normal speed of the fan. The speed was then altered to the required figure, the manometer was watched until it gave a steady reading, and then the other set of observations was started. The interval between the sets of observations was about fifteen minutes, and a set usually occupied, as a general rule, about ten minutes. Whenever possible at least two sets of observations were taken with the fan stopped. This time between tests, given above as fifteen minutes, was found during the preliminary tests and used in those which followed. It is interesting to note that this figure has been verified by Mr.R.A.H.Flugge-de Smidt[1]. Thus, we were able to

[1] "The Effect on the Ventilating Current of Stopping and Starting a Mine Fan." Journ. Chem., Met.and Min.Soc.S.Africa, 1925, Vol.XXVI, p.110.

run our sets of observations in fairly quick succession. This was very fortunate for two reasons:-

(1) The stoppage which was caused in the normal ventilation of the colliery was not too prolonged, and

(2) The state of the external atmosphere had no time in which to alter very much - a very important fact.

Pulsating and eddying flow introduced difficulty in regard to obtaining suitable measuring stations, at which the flow was sufficiently regular. Usually the gauge was taken and the velocity measured about 40 feet from the fan, but at mines Nos.1, 5, 9 and 12 (see **table** 1.), the distance was somewhat less. As eddying and pulsation are considerable near the shaft-insets and fan-inlets, regular flow was practically unobtainable. For this reason any elaborate system of air measurement was really useless and was discarded; the quantity of air was measured by traversing the area of the fan drift with a regular motion in a serpentine path, generally for three minutes. The measurements were taken two or three times. The anemometer was a zero-setting instrument, calibrated frequently in the Mining Department, Heriot-Watt College on the anemometer - "table". (See Cooper's work). The results thus obtained will, if anything, tend to the high side. Pulsating flow is also objectionable in ascertaining pressure difference, but not to the same extent as in air-measurement, as its influence can be reduced considerably. The ventilating pressure was obtained by means of an inclined gauge containing petrol (Specific Gravity 0·758) and consisting of two parallel tubes, 5 feet in length and $\frac{3}{4}$ inch in bore. The inclination of the tubes was measured by a clinometer and was generally adjusted to give an amplification of 10 to 1; for this factor, the angle of inclination was 7 degrees 35 minutes. During a set of measurements, the gauge was under observation the whole time and it was read at short intervals, - first with one and then with the other limb connected to the drift - and the mean was taken

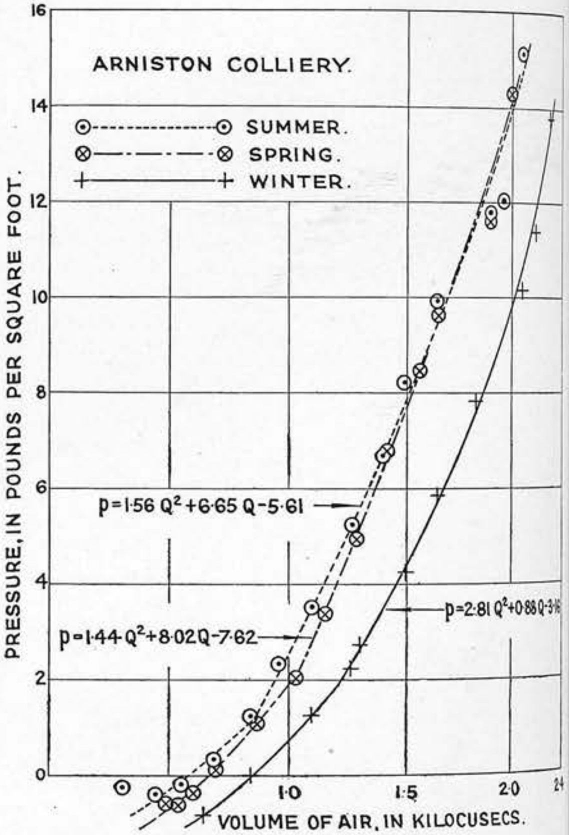


FIG. 23.—GRAPH OF OBSERVATIONS RECORDED AT ARNISTON COLLIERY.

MAXIMUM SHAFT DEPTH=960 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density in shaft, in pounds per cubic foot.		
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.	Summer test.
Upcast	61·93	62·53	63·00	0·075	0·076	0·075
Downcast	43·72	50·10	56·70	0·078	0·078	0·076

The calculated natural ventilating pressure due to the shafts alone was—

Winter test, 2·78 pounds per square foot.
Spring ,, 2·15 ,, ,, ,,
Summer ,, 1·13 ,, ,, ,,

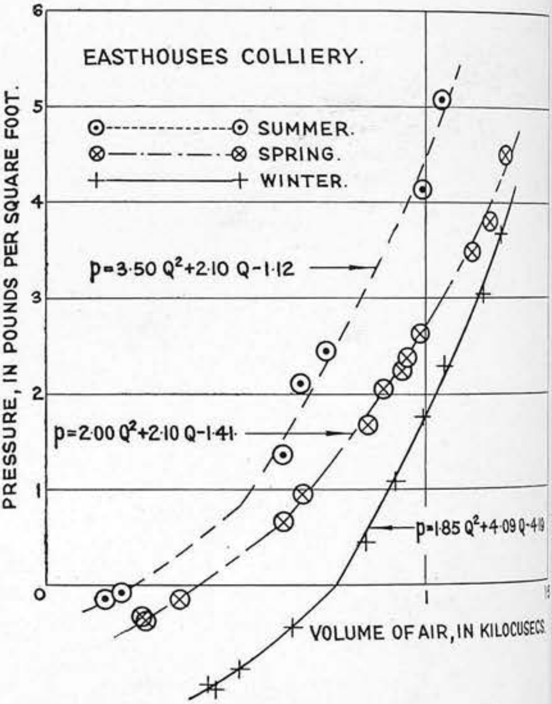


FIG. 24.—GRAPH OF OBSERVATIONS RECORDED AT EASTHOUSES COLLIERY.

Incline.	Average incline temperature, in degs. Fahr.			Average air-density in incline, in pounds per cubic foot.		
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.	Summer test.
Upcast	56·27	55·75	54·00*	0·078	0·0778	See note below.
Downcast	43·76	53·48	57·70*	0·081	0·0780	See note below.

The calculated natural ventilating pressure due to the inclines alone was—

Winter test, 4·41 pounds per square foot.
Spring ,, 0·91 ,, ,, ,,
Summer ,, (see note below).

* These temperatures were taken only at the surface; the information is not sufficient to calculate the natural ventilating pressure.

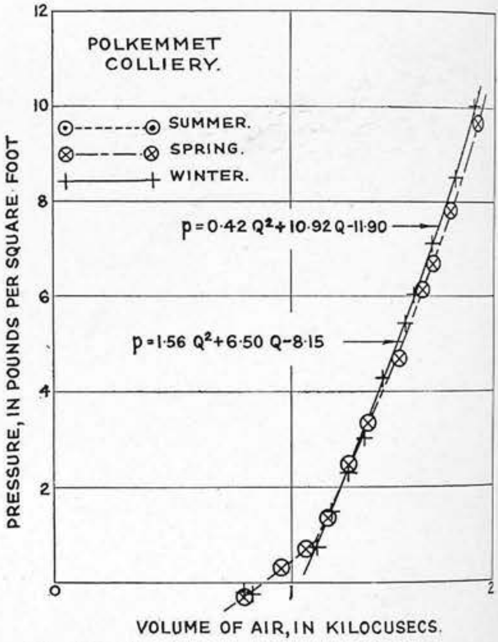


FIG. 25.—GRAPH OF OBSERVATIONS RECORDED AT POLKEMMET COLLIERY.

MAXIMUM SHAFT DEPTH=1,572 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.		Average air-density in shaft, in pounds per cubic foot.	
	Winter test.	Spring test.	Winter test.	Spring test.
Upcast	66·78	64·43	0·074	0·076
Downcast	46·64	56·25	0·078	0·077

The calculated natural ventilating pressure due to the shafts alone was—

Winter test, 6·63 pounds per square foot.
Spring ,, 1·36 ,, ,, ,,

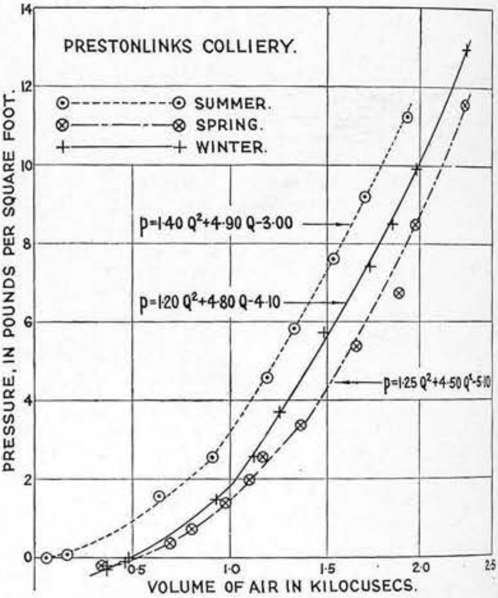


FIG. 26.—GRAPH OF OBSERVATIONS RECORDED AT PRESTONLINKS COLLIERY.

MAXIMUM SHAFT DEPTH=400 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density in shaft, in pounds per cubic foot.		
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.	Summer test.
Upcast	53·30	53·60	57·31	0·077	0·078	0·076
Down-cast	39·47	44·06	64·30	0·080	0·080	0·075

The calculated natural ventilating pressure due to the shafts alone was—

Winter test, 1·07 pounds per square foot.
Spring ,, 0·75 ,, ,, ,,
Summer ,, −0·023 ,, ,, ,,

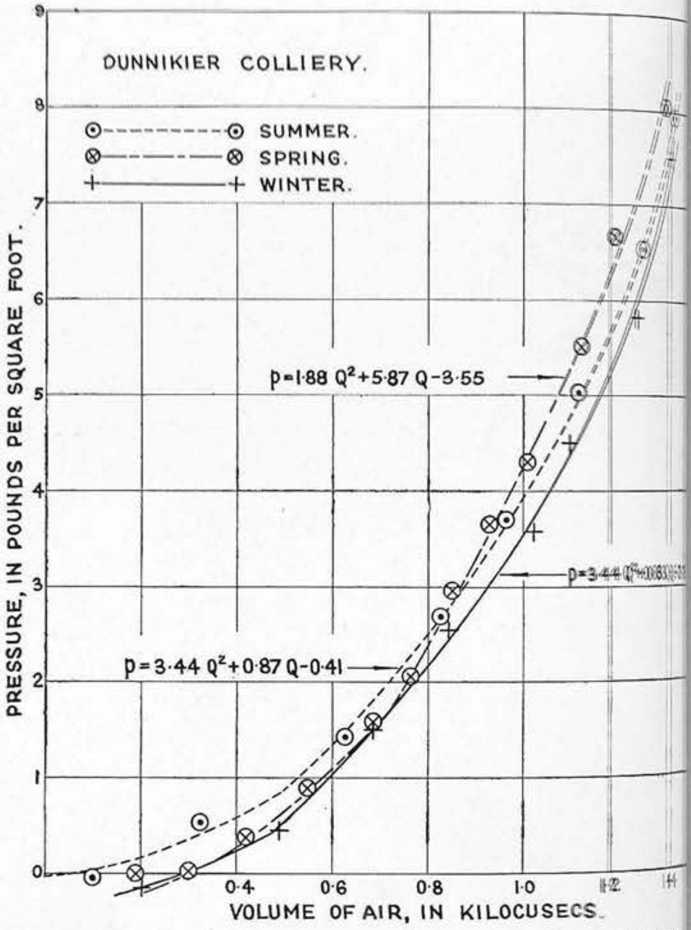


FIG. 27.—GRAPH OF OBSERVATIONS RECORDED AT DUNNIKIER COLLIERY

MAXIMUM SHAFT DEPTH=701 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density in shaft, in pounds per cubic foot.		
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.	Summer test.
Upcast	54·60	55·81	60·15	0·078	0·076	[illegible]
Downcast	42·11	48·84	59·25	0·080	0·078	[illegible]

The calculated natural ventilating pressure due to the shafts alone

Winter test, 1·58 pounds per square foot.
Spring ,, 0·895 ,, ,, ,,
Summer ,, 0·64 ,, ,, ,,

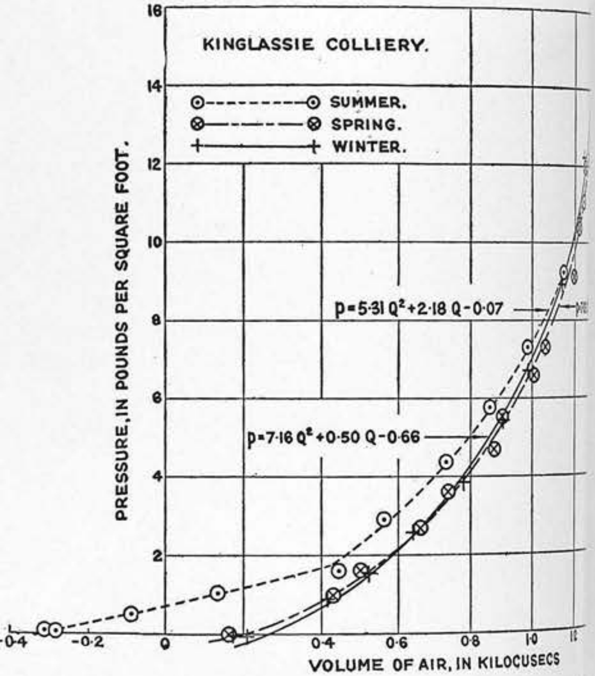


FIG 28.—GRAPH OF OBSERVATIONS RECORDED AT KINGLASSIE

MAXIMUM SHAFT DEPTH=1,050 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density pounds per	
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.
Upcast	58·74	58·04	59·99	0·074	[illegible]
Downcast	47·43	50·44	61·10	0·076	[illegible]

The calculated natural ventilating pressure due to the shafts

Winter test, 2·26 pounds per square foot.
Spring ,, 1·60 ,, ,, ,,
Summer ,, −0·112 ,, ,, ,,

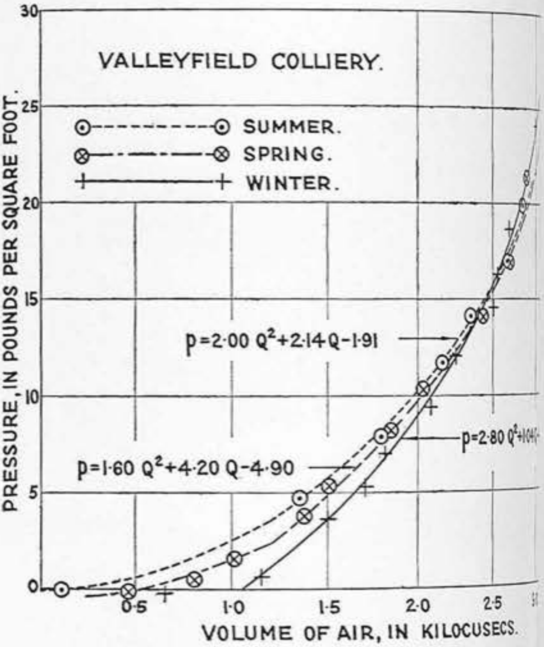


FIG. 29.—GRAPH OF OBSERVATIONS RECORDED AT VALLEYFIEL

MAXIMUM SHAFT DEPTH=1,160 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density in pounds per cubic	
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.
Upcast	56·20	59·77	61·26	0·077	0·077
Downcast	37·11	50·13	63·62	0·080	0·079

The calculated natural ventilating pressure due to the shafts

Winter test, 4·48 pounds per square foot.
Spring ,, 2·05 ,, ,, ,,
Summer ,, 1·18 ,, ,, ,,

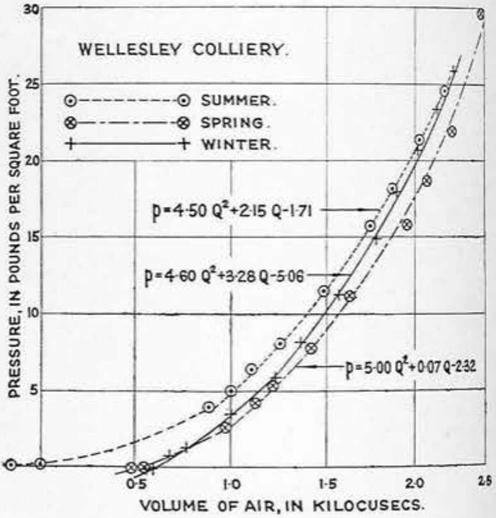


FIG. 30.—GRAPH OF OBSERVATIONS RECORDED AT WELLESLEY COLLIERY.

MAXIMUM SHAFT DEPTH=1,554 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.			Average air-density in shaft, in pounds per cubic foot.		
	Winter test.	Spring test.	Summer test.	Winter test.	Spring test.	Summer test.
Upcast	69·08	66·36	69·67	0·077	0·076	0·076
Down-cast	44·62	50·06	66·92	0·080	0·078	0·077

The calculated natural ventilating pressure due to the shafts alone was—

Winter test, 5·10 pounds per square foot.
Spring ,, 2·95 ,, ,, ,,
Summer ,, 0·845 ,, ,, ,,

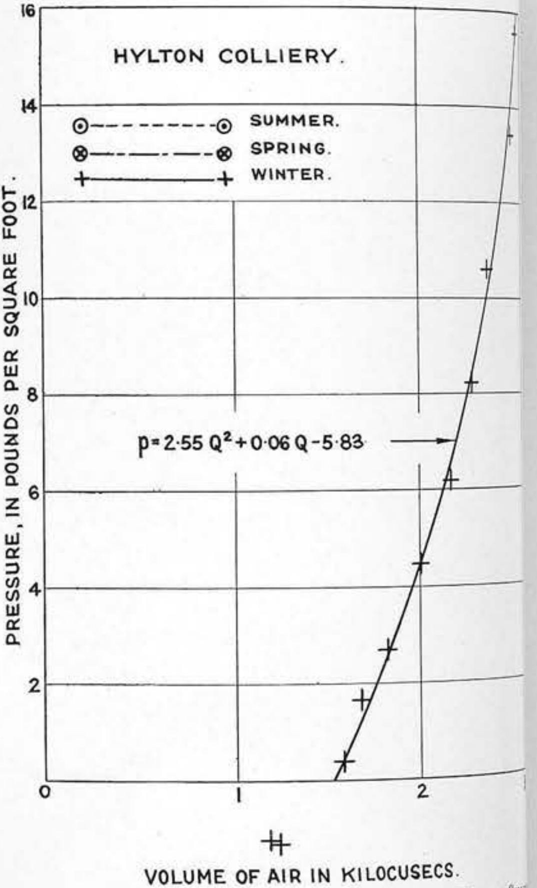


FIG. 39.—GRAPH OF OBSERVATIONS RECORDED AT HYLTON COLL

MAXIMUM SHAFT DEPTH=1,761 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.	Average air-density in shaft, in pounds per cubic foot.
	Winter test.	Winter test.
Upcast	66·23	0·075
Downcast	43·75	0·081

The calculated natural ventilating pressure due to the sh alone for the winter test was 8·37 pounds per square foot.

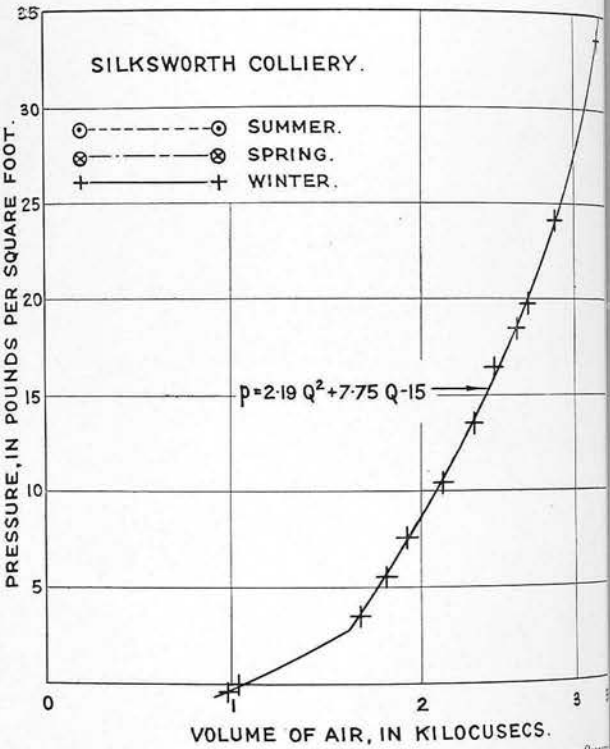


FIG. 32.—GRAPH OF OBSERVATIONS RECORDED AT SILKSWORTH COLLI
MAXIMUM SHAFT DEPTH=1,741 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.	Average air-density in shaft, in pounds per cubic foot.
	Winter test.	Winter test.
Upcast	66·16	0·074
Downcast	44·51	0·079

The calculated natural ventilating pressure due to the shafts alone the winter test was 7·76 pounds per square foot.

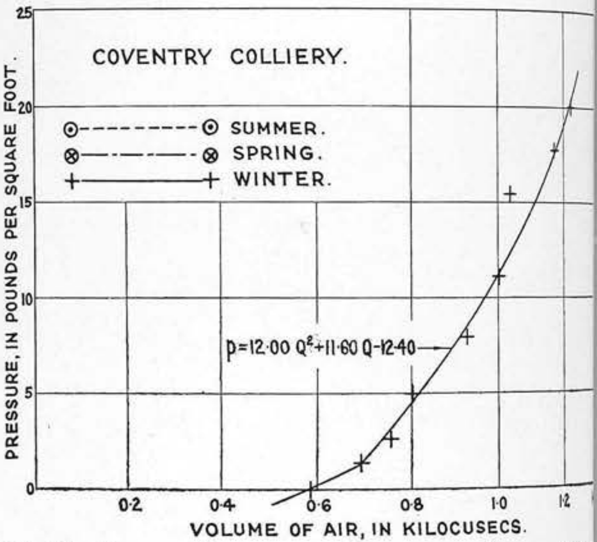


FIG. **33**.—GRAPH OF OBSERVATIONS RECORDED AT COVENTRY COLLIERY. MAXIMUM SHAFT DEPTH=2,138 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.	Average air-density in shaft, in pounds per cubic foot.
	Winter test.	Winter test.
Upcast	63·45	0·076
Downcast	46·84	0·079

The calculated natural ventilating pressure due to the shafts alone for the winter test was 6·45 pounds per square foot.

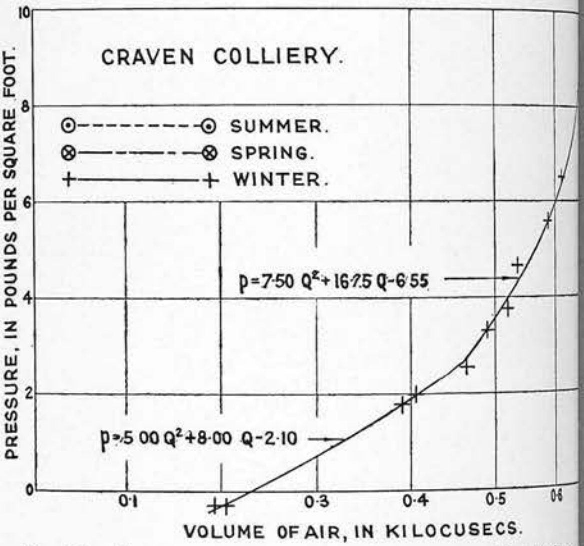


FIG. 34.—GRAPH OF OBSERVATIONS RECORDED AT CRAVEN COLLI

MAXIMUM SHAFT DEPTH=255 FEET.

Shaft.	Average shaft temperature, in degs. Fahr.	Average air-densit in shaft, in pou per cubic foo
	Winter test.	Winter test.
Upcast	52·05	0·077
Downcast	38·08	0·079

The calculated natural ventilating pressure due to the shafts alo the winter test was 0·66 pound per square foot.

of the considerable number of readings so obtained. The relatively large bulk and inertia of the liquid in the gauge and the narrow diameter ($\frac{1}{4}$ inch) of the "compo" piping connecting it to the point of observation in the drift, had the effect of damping out much of the pulsation. In the drift, the "compo" piping was connected to a brass mouth-piece, pointing directly to windward, placed mid-high in the road, and set one-seventh of the width from one side. All the readings were, therefore, of the "dynamic" or total water-gauge.

Experimental Results:- (1) The observations recorded are given in the appendix; they are also shown graphically (Figures 23-72 inclusive). We shall now consider the curves (Figures 23-34). Fan-drift depressions, in pounds per square foot, are plotted as ordinates, and fan-drift air volumes in kilocusecs (thousands of cubic feet per second) as abscissæ. Measurements were obtained under winter, spring and summer conditions at seven mines, for the winter and summer periods at one, and for winter at the four English collieries. The effect of the variation in natural ventilation on the mine characteristics is shown by the graphs. In some cases, e.g.Easthouses Colliery, (Figure 24) the difference between the summer and winter characteristics is marked; in others, e.g. Kinglassie Colliery (Figure 28), it is much less noticeable. Again, the spring curve does not always lie between the winter and the summer curves, as, for example, at Prestonlinks Colliery, (Figure 26), in which case the graphs appear to occupy each others positions. The presence of underground fans, which, as was remarked before, could not be stopped for our purposes, complicates the question in this case; in others, the presence of steam pipes presents an unknown and probably variable factor. Again, some of the graphs cross each other as in the case of Valleyfield Colliery (Figure 29).

Thus the graphs show how complicated is the problem to be solved and how useless it would be to do more at this stage than express in very general terms the relation between air-quantity and ventilating-pressure for a mine. It is extremely unfortunate that our unfinished series of experiments were on the simpler, independent English ventilating systems. It would seem that the proper procedure now would be to investigate more fully two mines, one developed and the other a new winning, both with independent systems. It was intended to do this, taking tests every other week-end at each pit for a year, but, so far, force of circumstances has unfortunately prevented this.

Still, with what information there is available, can any explanation be given for those numerous apparent anomalies? The effect of time must not be overlooked in our search for an answer. The tests were carried out at intervals of three months or more, and no active mine keeps constant during this period. Thus, the tests were carried out on a different subject each time. It was thought that this difference would be small and would not affect such a comparison as was made. Considerable changes in the ventilating systems would have an appreciable effect but in no instance can any information about such a change be procured. It would seem that the only alterations are the minor ones in the ordinary working of the pits. This would point to the large effect of which these small alterations would seem to be capable. Another clue may be found in the fact that changes in the natural ventilating pressure are apt to be irregular in distribution. If, for example, there are two seams, one shallow and the other deep, and these are connected to the same upcast and downcast shafts, an alteration of natural ventilation would have more influence on the deeper than on the shallower workings; the resultant effect, as indicated by fan-drift measurements, will depend upon which seam is the principal user of air. Similarly, in a mine with workings to the rise and dip in an inclined seam, a change in natural ventilation affects not only the total quantity of air passing through the mine, but also the quantities in each district. Also, consider a ventilating system, which is not totally independent, but is connected to some other, not for ventilating purposes, but for haulage, travelling etc.: the efficiency of the barriers between the two systems will not necessarily be constant for the different tests. This would mean that the effect of the above mentioned two forces may vary with the efficiency of isolation, as we may in reality be dealing with a totally different subject in each test. In addition, the fan in the adjoining ventilating system would have some effect.

For these reasons, the characteristic curves taken at intervals of a few months tend to differ in shape as well as in position, with regard to the horizontal axis. Another reason thus appears for an immediate investigation such as has been mentioned previously.

The Zone of Unstable Flow. This more intensive investigation would be useful in another light, as in almost every case the graphs (Figures 23-34) are affected by a "kink", indicating some change in law. Several recent papers such as those of Hay and Cooke, Hodgson, Penman and Wetherell, and D.and J.S. Penman have made known the conceptions of turbulent and stream-line flow, of the upper and lower critical velocities, and of the region of unstable flow lying between those critical speeds. In a mine turbulent flow is undoubtedly most in evidence. However, stream-line flow, either partly or wholly, may be found in parts of the mine where the air-velocity is low, or where the passage is small in section - as, for example, in leakage through waste. With fan-drifts, shafts, etc. of the usual order it would appear that stream-line flow is the dominant factor only when the air-velocity is considerably below 5 feet per minute. The effect of pure stream-line flow upon the characteristic curve can, therefore, be neglected.

The first to recognise that the mine characteristic curve possessed a "kink" were Penman and Wetherell, who found in one case that the indices in equations of the type $p = \rho Q^n$ altered when the quantity passing was 20,000 cubic feet per minute. Below that figure, the index was 1·26, but, when this quantity was exceeded, the index was 1·78. At the pits tested during this investigation, a "kink" can be traced in almost every curve. This break in continuity may be very marked, as at Polkemmet Colliery (Figure 25) or barely discernible, as at Prestonlinks Colliery (Figure 26) in the summer. Nevertheless, after careful consideration, any doubt as to its presence must be dispelled. At the beginning of the investigation, this break was not expected, but when its presence was suspected, more points in the curves were obtained at low speeds. Many of the cases, in which the presence of the "kink" appears somewhat doubtful, have just few enough points on the curve in this region.

It would appear that there is some dominant factor, which effects this break. When one considers the large number of individual air passages in a mine, one would expect that any alteration in the law of air-flow would be gradual and, when represented graphically, indistinct. However, this must be discredited, and search made for some other cause. A dominant type of resistance suggests itself. Inbye air-roads are of too varied a character to permit of anyone throwing the blame there. From calculations, it has been found that the shaft resistances are too small in comparison with the resistance of the mine to have this effect. The main intakes and main returns are now left; they would seem to offer a possible explanation, especially the main returns, which usually have higher resistances than intakes. The pressure survey of the air-routes in the mines of the Powell Duffryn Steam Coal Company, Ltd., now proceeding under the direction of Major E. Ivor David, may be of great use in solving this riddle.

It is interesting to note that Professor Hay and Mr.Cooke (see Hay's work) have obtained a similar graph for a roadway at Rockingham Colliery. Natural ventilation was not a factor in this case of a level road; yet a "kink" may be detected in the curve. Those workers did not, as was done in the instances described, use an anemometer, but a specially designed instrument. The anemometer was suspected to some extent of being the cause of the "kink", as it was realised that it was not a really accurate instrument; it must now be freed from this suspicion. This acquittal

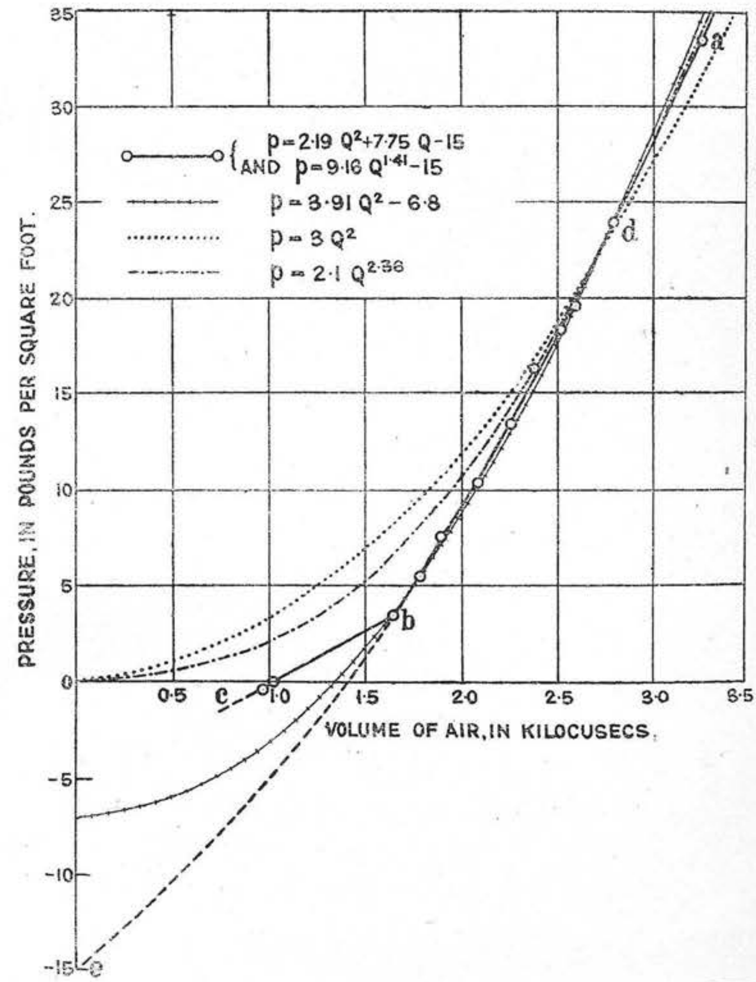


FIGURE 35. — ANALYSIS OF WINTER CURVE OF SILKSWORTH COLLIERY.

would seem quite justified, as the velocities at the "kink" were determined in each case, and those velocities varied to a really remarkable extent, leaving no doubt, in the writer's opinion, as to the suitability of the anemometer for the work it had to do.

<u>The Equation of the Mine Characteristic Curve</u>. The connexion between the air-volume in a mine and the fan-drift pressure is important, as, once this relationship is known, it is easy to calculate the fan-drift pressure required to produce any given volume of air under the conditions of natural ventilation and surface leakage obtaining at the time.

For ease of handling, one case, the Silksworth (winter) curve, will be considered in detail (see Figure 35). The normal running of the fan (speed, 246 revolutions per minute; quantity, 196,200 cubic feet per minute; ventilating pressure, 33·44 pounds per square foot) is represented by the point a. Natural ventilation was in this case, as in many of the others, assisting the fan. The lowest point c was obtained when the fan was stationary and indicates a small negative gauge in the drift, due to the fact that air was passing through the fan (which had resistance). Pressures <u>below</u> the horizontal axis are really <u>positive</u>, but for graphical purposes, they are considered as <u>negative</u>, and the pressures <u>above</u> as <u>positive</u>.

The graph adbc does not pass through the origin O; this is the effect of natural ventilation. If the part b c were produced or extrapolated, it would meet the vertical axis at a point well below the origin, i.e., a negative gauge would be required to stop the flow of air.

The working range of the mine ventilating system is well above the point b, and adb is the important part of the graph. The equations to be considered and the corresponding equations for other curves relate only to such parts of the graphs,

(a) Equations of the types $p = \rho Q^2$ and $p = \rho Q^n$. Attempts were made to satisfy the relationship between air-quantity and fan-drift pressure by equations of those types, but the uselessness of these types is proved by the curves constructed from our experimental results. The graphs of both those equations pass through the origin, while the actual constructed curves do not. For the Silksworth series, the curve $p = 3Q^2$ is about the best of the type (see Figure 35), but nowhere does its course follow the line a d b. Also, it passes through the origin, but the line a d b passes far from that point. In the Silksworth case, this form of equation is really useless. For the upper part of the summer curve for Dunnikier Colliery (Figure 27), the curve $p = 5\ Q^2$ is quite satisfactory; if we neglect a bulge near the critical point, a similar statement applies to the curve $p = 3{\cdot}22\ Q^2$ for the Prestonlinks summer curve (Figure 26). Those two are only exceptional cases, however, and probably only hold good for a special state of natural ventilation. Generally speaking, only in a few cases does this type apply to the curves, even for a limited section: instead, the two curves tend to cut one another. We can quite readily dismiss equations of the type $p = \rho Q^2$ as quite useless for representing the curves obtained.

Equations of the other type mentioned, i.e. $p = \rho Q^n$ can be found to suit short portions of any of the curves. This formula has been used by previous experimenters, who obtained values of indices varying from 1·7 to 1·9 - always less than 2; this was thought to be due to the fact that in the network comprising the mine ventilating system, the flow of the air was neither of the turbulent variety ($p \propto Q^2$) nor of the stream-line type ($p \propto Q$), but was mixed, giving an index between 1 and 2, depending upon the relative proportions of each type present. This reason, however, does not explain why the best equation of this type for the upper portion (covering the fan's working range) of the Silksworth graph (Figure 35) comes to be $p = 2{\cdot}19\,Q^{2.36}$; nor why the indices for the equivalent parts of the winter curves for Craven (Figure 34), Wellesley (Figure 30), Polkemmet (Figure 25), Coventry (Figure 33), and Hylton (Figure 31) are 2·3, 2·5, 3·2, 3·5 and 4·0 respectively.

The main factors in this value are the position of the "kink" b (Figure 35) with regard to the origin, and the slope of the curve above b. When b lies well to the right of the origin, the main part a b of the curve is shifted correspondingly; when we try to use an equation of the type $p = \rho Q^n$ for the representation of the relationship, a high value of n is required. When b a is steep, n needs to be bigger still. There are two influences tending to take b to the right, (a) a large region of unstable flow i.e. a lengthening of c b, and (b) a large natural ventilation assisting the fan. As regards the slope of b a, it is noticed that the greater the mine resistance, the steeper is b a.

If b a had been moved bodily through 1 unit first to the left and then to the right, i.e. if b had been points where $Q = 0{\cdot}65$ and $2{\cdot}65$ respectively, instead of 1·65, the index would have altered for the two cases to 1·54 and 3·25 (c.f. 2·36).

An increase in n involves a decrease in ρ; when n is large (due to the steepness of the curve) ρ is small; so ρ in this type of equation cannot measure mine resistance, as it is possible to select instances in which a high value of ρ corresponds to a low resistance, and vice versa.

It must now be concluded that equations of the types $p = \rho Q^2$ and $p = \rho Q^n$ cannot express the relationship between air-quantity and fan-drift pressure. An equation of the type $p = \rho Q^n$ may be found to fit the experimental curves to some extent; the values of ρ and

and n are merely mathematical figures however and cannot be taken to have any physical significance. This type is also of practically no value.

(b) Equations of the type $p = AQ^2 + BQ - C$. In 1874, J.C.Fairweather of Glasgow published the results of experiments on the spinning of vanes at different velocities (v) in still air;[1] he found that the force required to keep the vanes in motion could be represented by the series $a_1 v + a_2 v^2 + a_3 v^3 \ldots$, where a_1, a_2, a_3, etc.were coefficients. In the problem being discussed, the air moves and the solid surfaces are at rest; the similarity of the two questions is, however, sufficient to justify an attempt to use Fairweather's work. After trials, it has been found that for this problem any powers of v higher than the second introduce mathematical complications not justified by the slightly increased accuracy. Another modification is required. Few of the actual curves pass through or even near the origin; an additional term must be included to demonstrate this. From these considerations and after altering the symbols of the series to suit the present purpose, it was thought by Professor Henry Briggs,[2] that an equation such as $p = AQ^2 + BQ - C$ might solve the problem. The last term in the expression is negative when natural

[1] "On the Resistance of the Air to the Motion of Fans", Procs.Roy.Soc.Edin., 1874, vol. Vlll, p.351.

[2] "Fan Problems", part 11, Coll.Eng.1925, vol. 11, p.247.

ventilation assists the fan, positive when it works against the fan.

Indeed of all equations tried, this is the one which most exactly fulfils the requirements and very often the agreement between it and the observed points is very close indeed. For Silksworth Colliery (Figure 35) the curve of an equation of this type, viz. $p = 2{\cdot}19\ Q^2 + 7{\cdot}75\ Q - 15$ closely follows the line b a, and when produced as shown dotted, cuts the vertical axis at e, a point 15 units below the origin.

(c) Equations of the type, $p = \rho\ Q^n - C$. It was also stated recently by Professor Briggs[1] that an index form of equation, such as $p = \rho\ Q^n - C$, could be found to fit the observed points very closely. The last term, $-C$, is the same as the corresponding term in $p = AQ^2 + BQ - C$. Turning again to the Silksworth winter curve, (Figure 35), it is found that $p = 9.16\ Q^{1.41} - 15$ is an expression almost as satisfactory as $p = 2.19\ Q^2 + 7.75\ Q - 15$, and when produced as considered before, it also cuts the axis at 15 units below the origin. Either of those forms just given may be considered to represent the portion b a. However, the quadratic form is the more logical and the easier to obtain from experimental data. The index form, on the other hand, provides a single factor ρ in place of the two coefficients A and B but this advantage is greatly reduced by the fact that the index n is a variable.

1"Fan Problems", part 11, Coll.Eng.1925, vol.11, p.247.

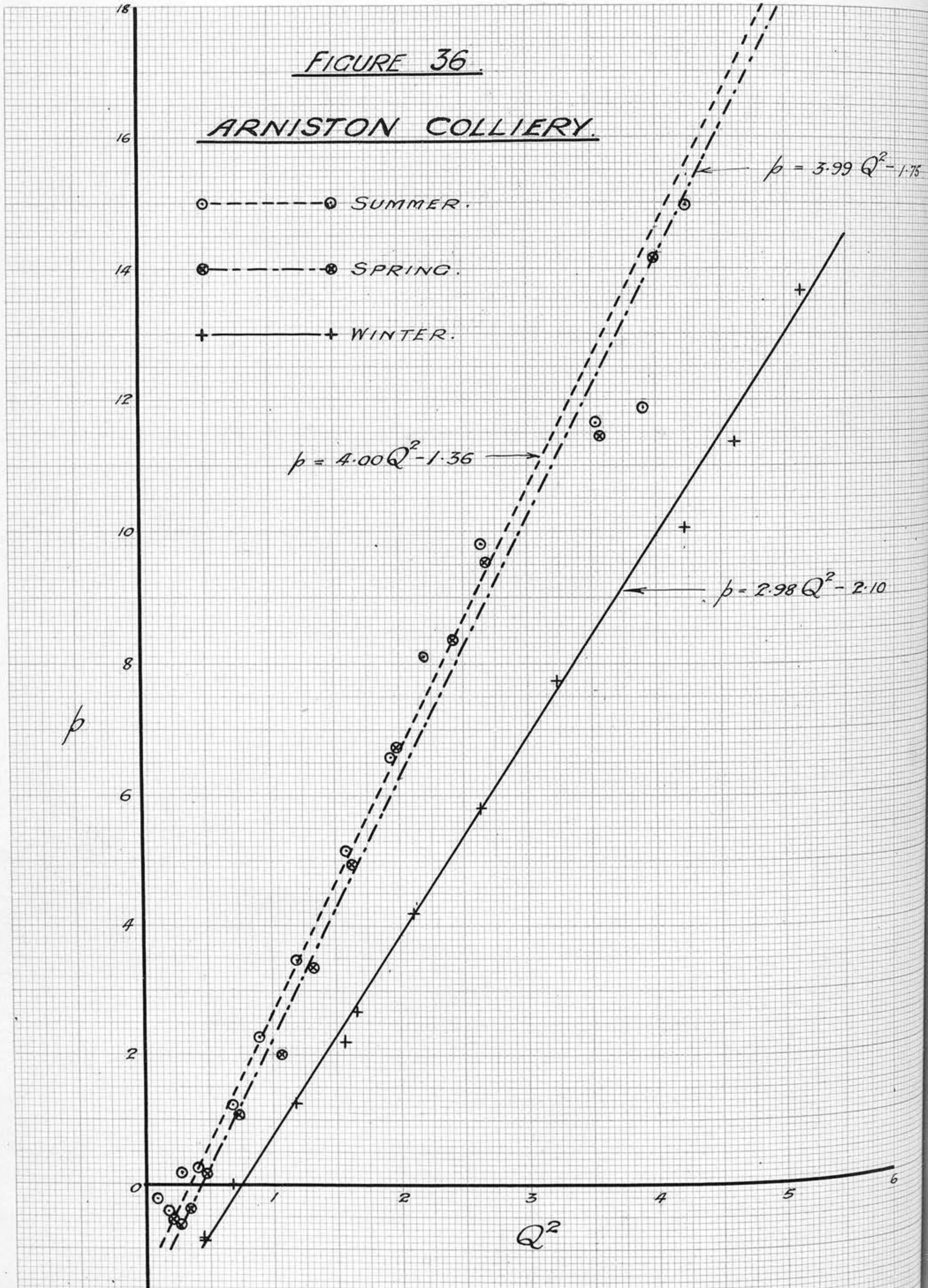


FIGURE 36.
ARNISTON COLLIERY.
SUMMER.
SPRING.
WINTER.
$p = 3.99 Q^2 - 1.75$
$p = 4.00 Q^2 - 1.36$
$p = 2.98 Q^2 - 2.10$
p
Q^2
18
16
14
12
10
8
6
4
2
0
-2
1
2
3
4
5
6

FIGURE 37.

EASTHOUSES COLLIERY.

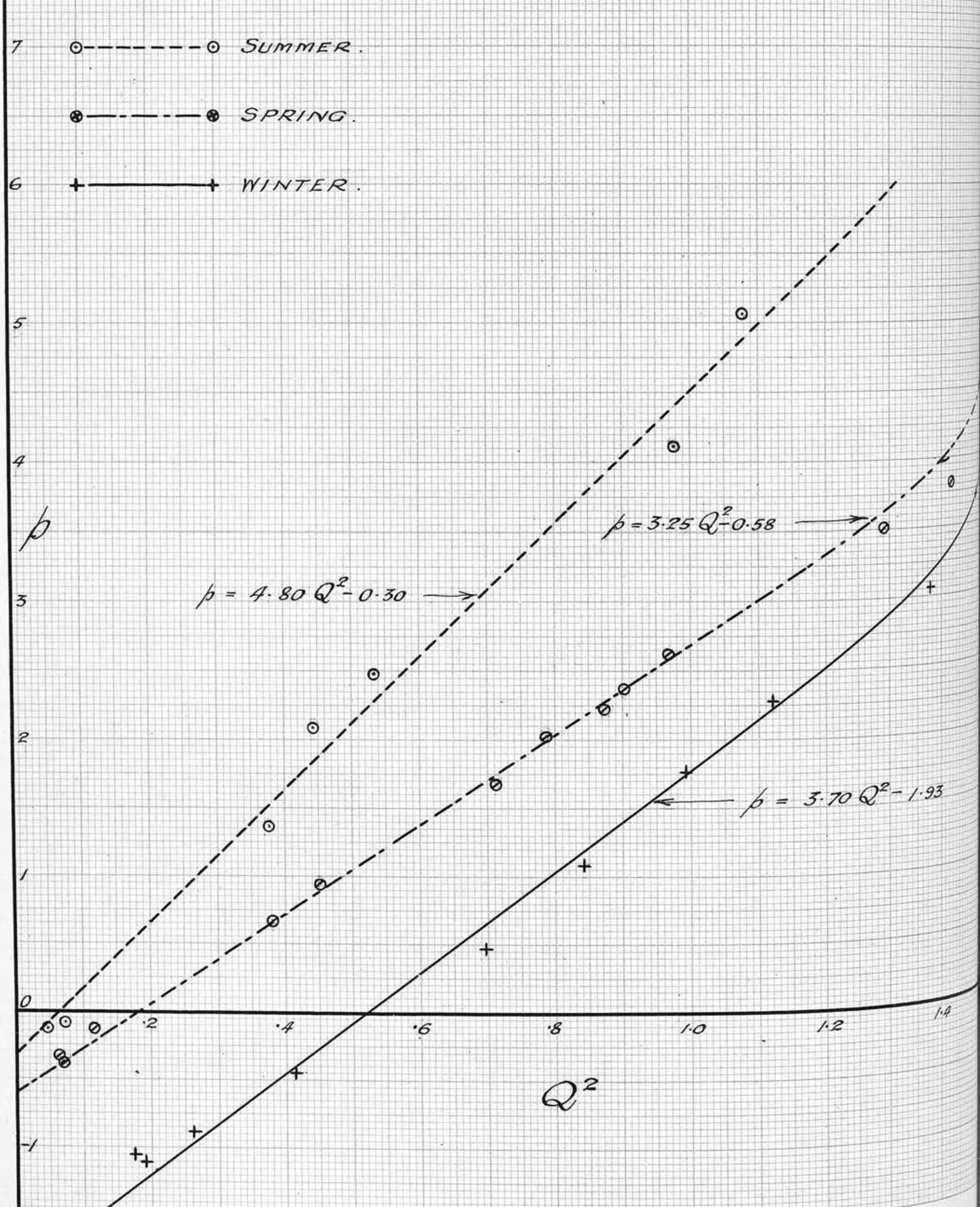


FIGURE 38.

POLKEMMET COLLIERY.

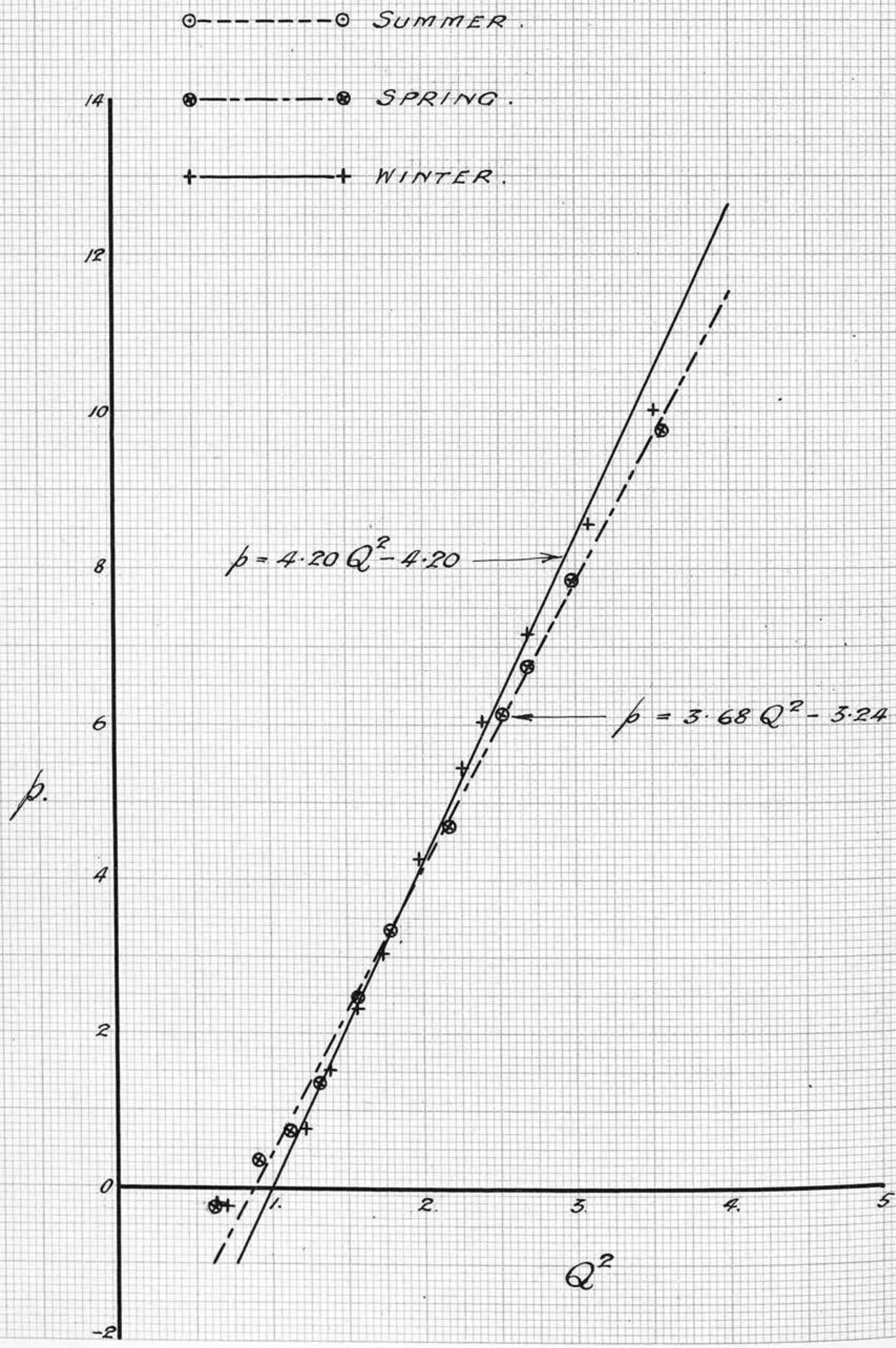
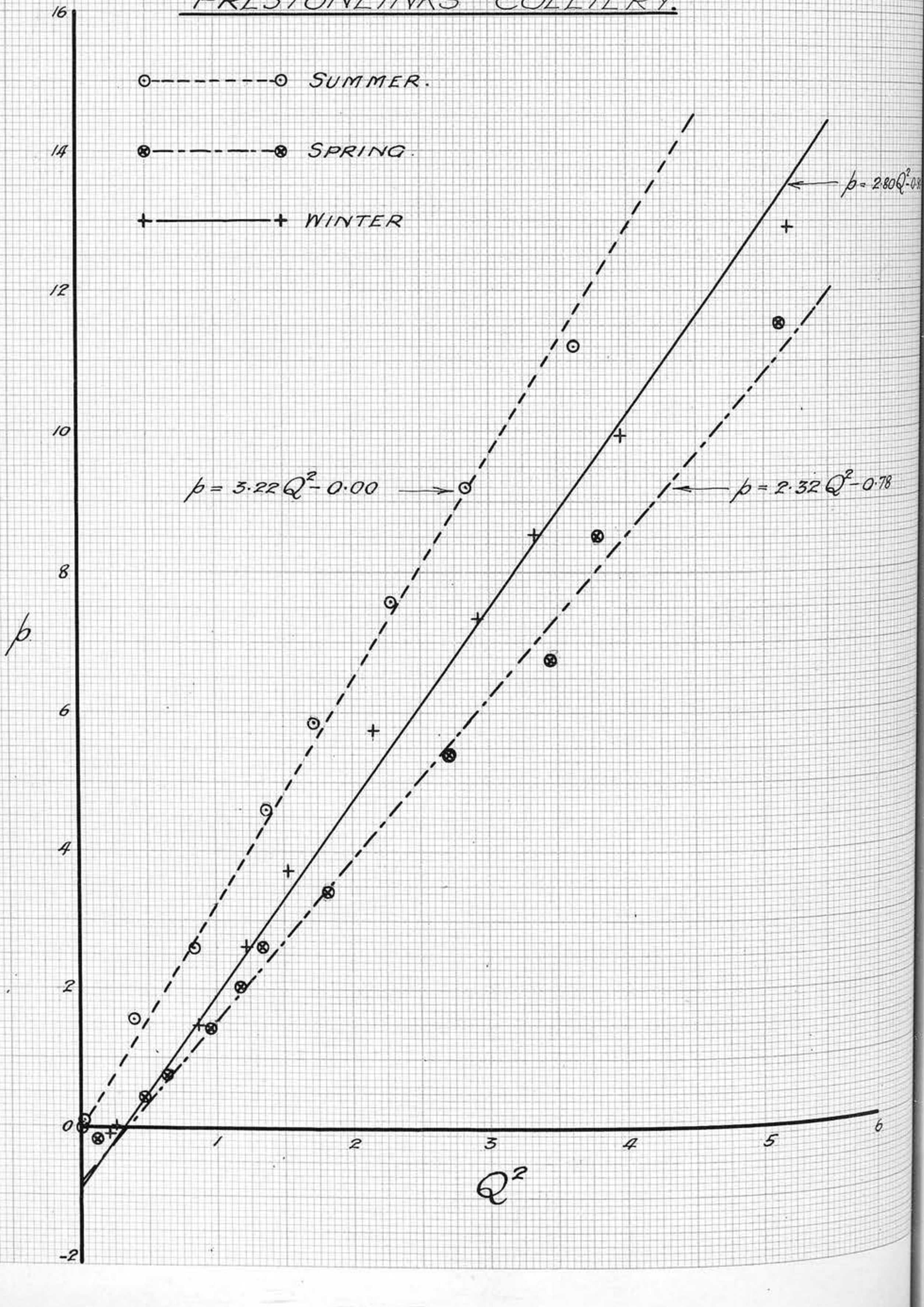


FIGURE 39.

PRESTONLINKS COLLIERY.



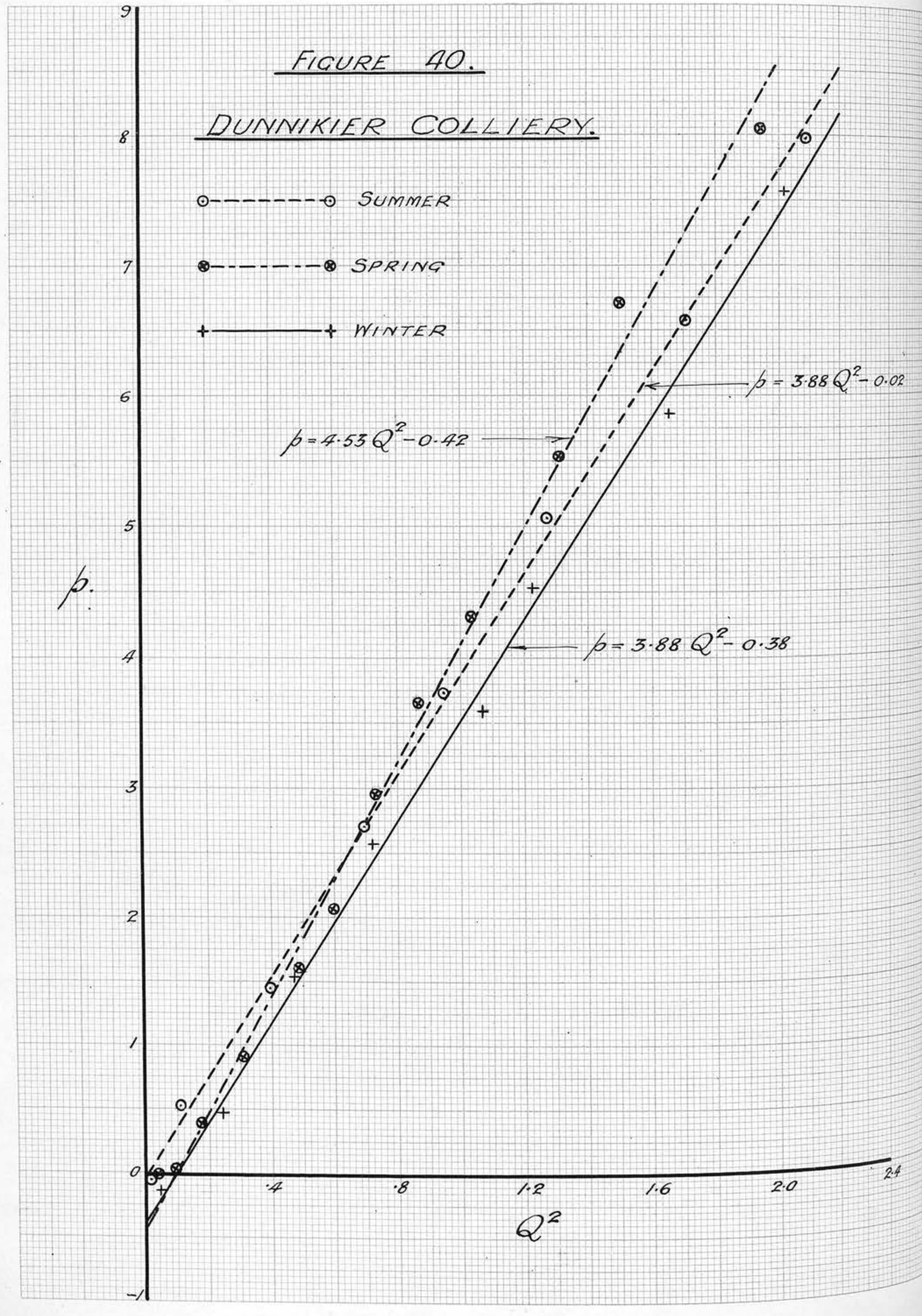


FIGURE 40.
DUNNIKIER COLLIERY.
SUMMER
SPRING
WINTER
p = 3·88 Q² − 0·02
p = 4·53 Q² − 0·42
p = 3·88 Q² − 0·38
p.
Q²
9
8
7
6
5
4
3
2
1
0
−1
·4
·8
1·2
1·6
2·0
2·4

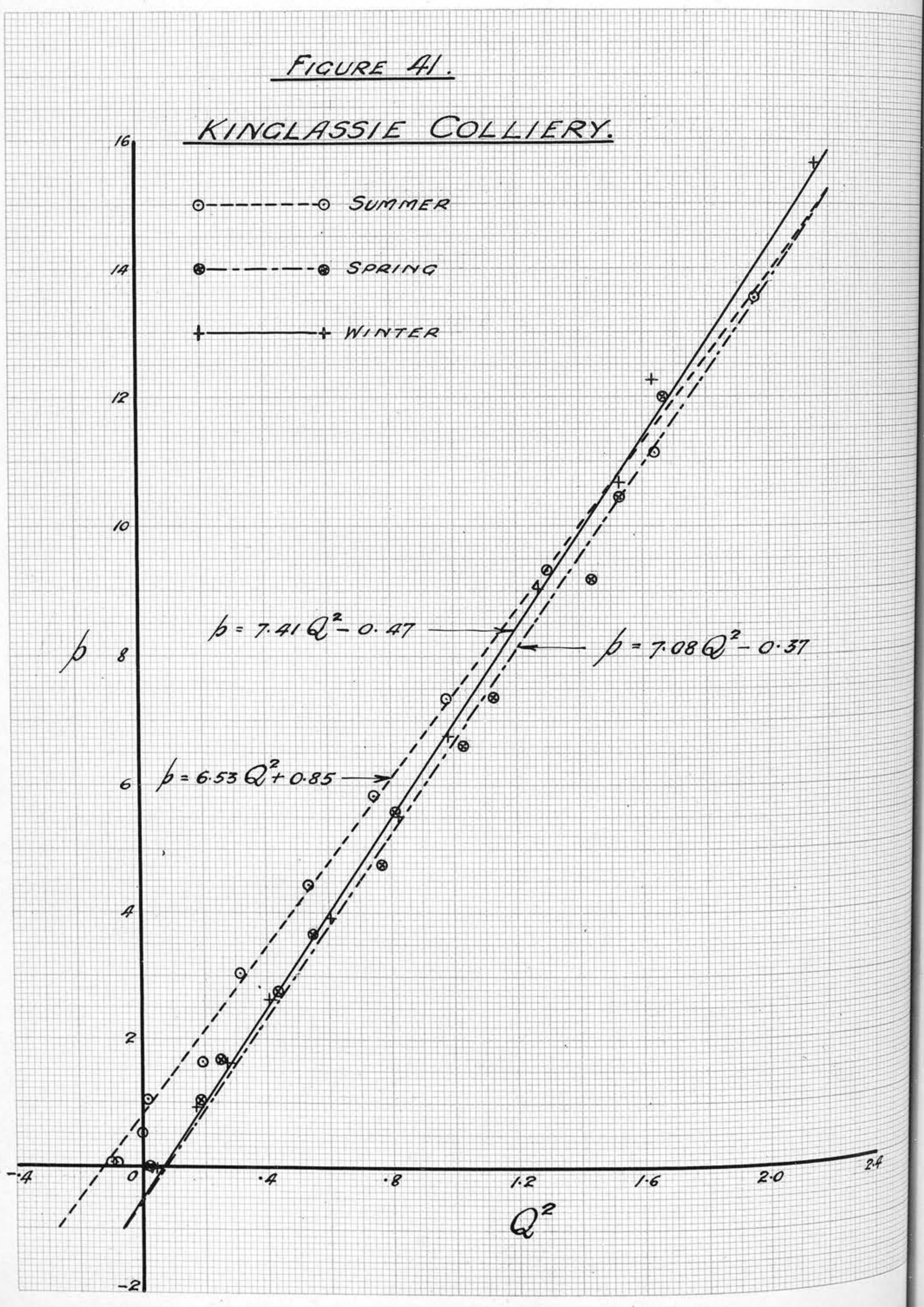
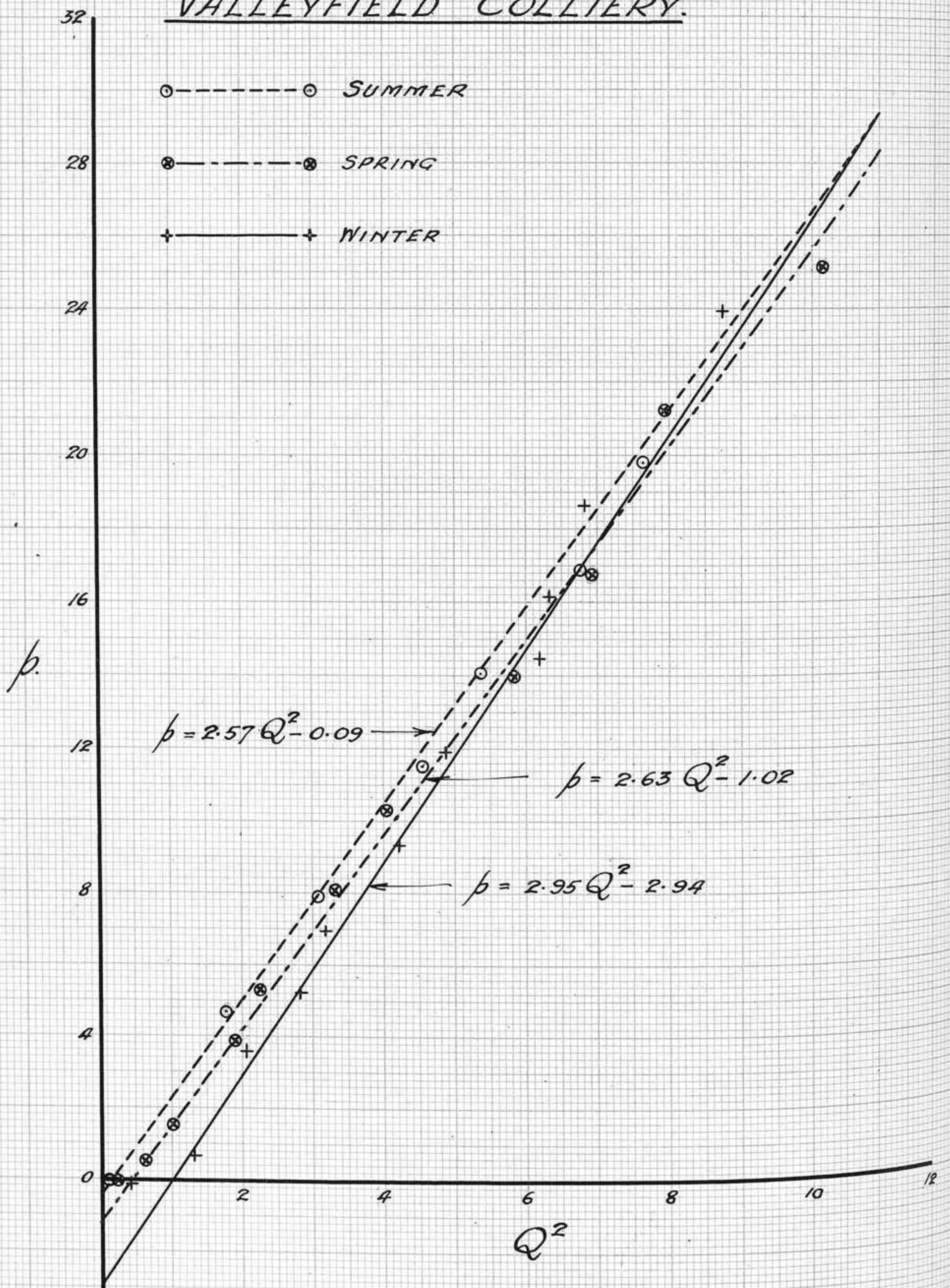


FIGURE 41.
KINGLASSIE COLLIERY.
SUMMER
SPRING
WINTER
p = 7·41 Q² – 0·47
p = 7·08 Q² – 0·37
p = 6·53 Q² + 0·85
p
Q²
16
14
12
10
8
6
4
2
0
-2
-·4
·4
·8
1·2
1·6
2·0
2·4

FIGURE 42.

VALLEYFIELD COLLIERY.



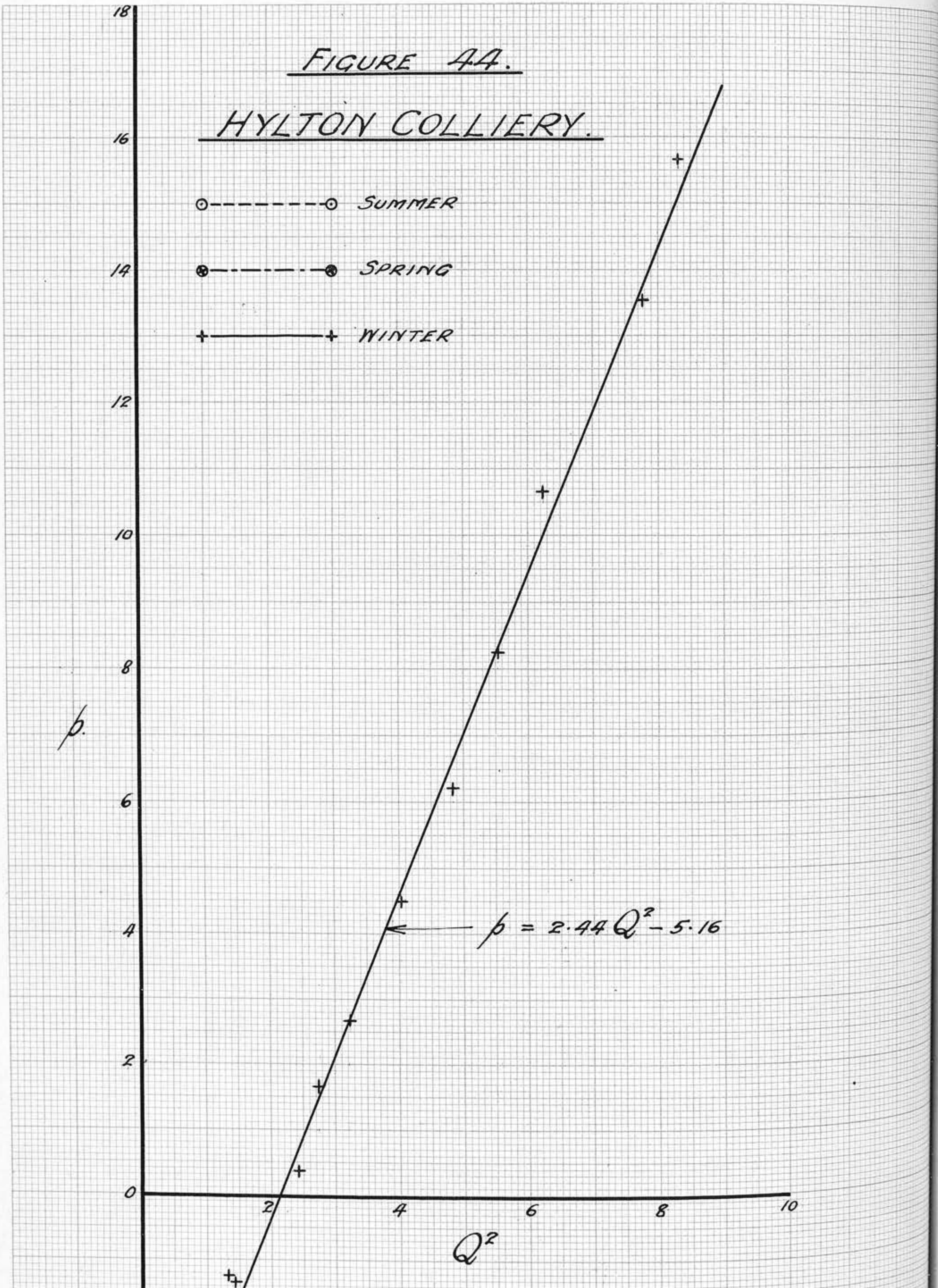
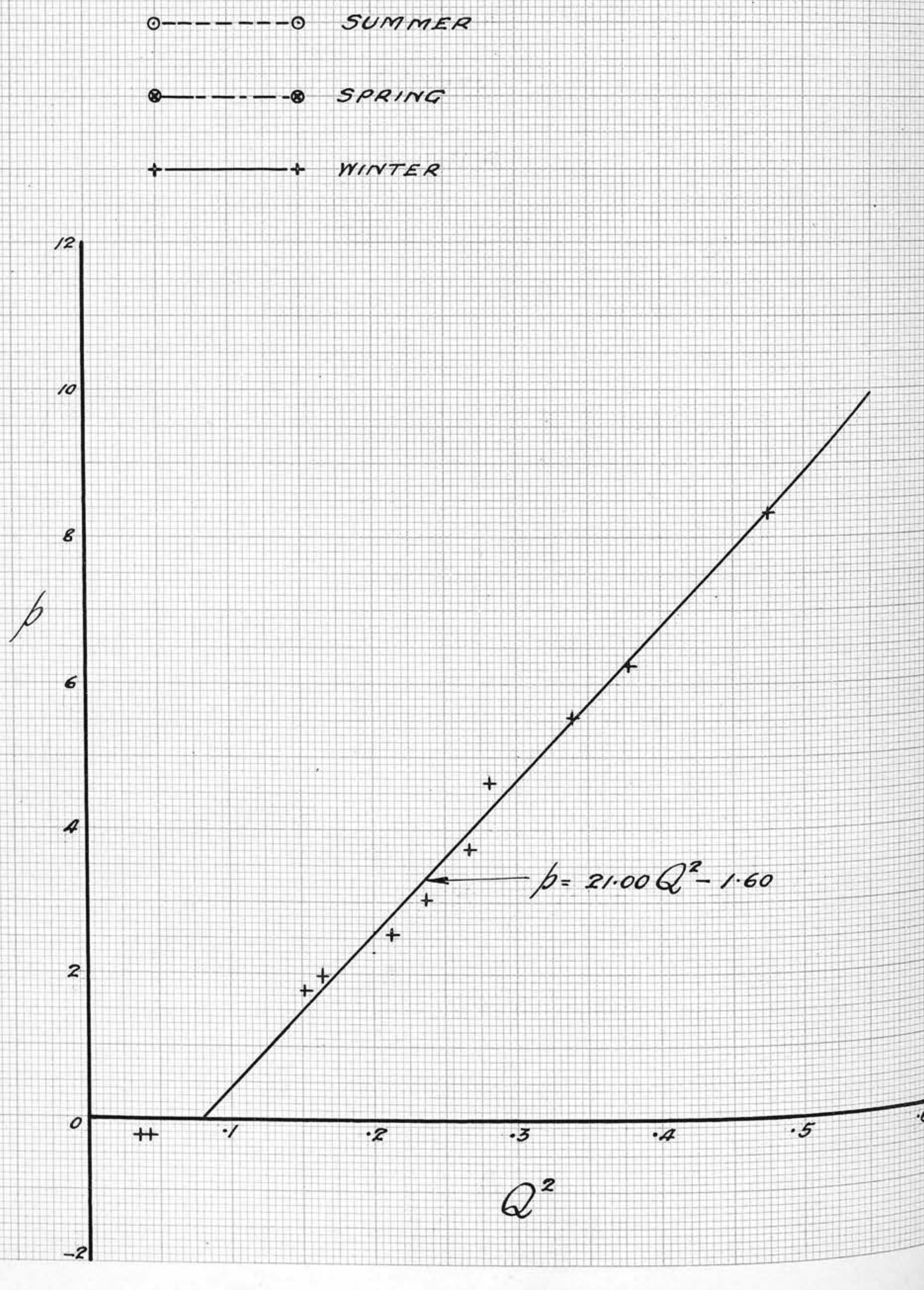


FIGURE 44.
HYLTON COLLIERY.
SUMMER
SPRING
WINTER
$p = 2{\cdot}44\,Q^2 - 5{\cdot}16$
p.
Q^2
18
16
14
12
10
8
6
4
2
0
-2
2
4
6
8
10

FIGURE 47.

CRAVEN COLLIERY.



(d) Equations of the type $p = \rho Q^2 - K$. This type is really a modification of the old square law. Attempts were made to fit the observed points with equations of this form. It was found that, while falling short of the quadratic form in accuracy, this type of equation provides a useful approximation. In figure 35, the expression $p = 3.91\ Q^2 - 6.8$ provides a satisfactory curve for the observed points. This case is by no means the best. Very good results have been obtained with this equation for the observed points at Wellesley, Dunnikier, Kinglassie, Valleyfield, Hylton, Coventry and Craven Collieries. If its limits are realised and not too much is expected from it, this type of equation will be of great value. As well as being simple and easily obtained, it provides a coefficient ρ, which is not modifed, as is the last type, viz., $p = \rho Q^n$, by a variable index n.

Instead of plotting the observed points as already described, a rather useful set of curves (Figures 36 - 47 inclusive) is obtained by plotting the value of p as ordinates as before, and the values of Q^2 as abscissae. By this artifice, a straight line is obtained for the observed points which we are considering. Thus, equations of this type can be readily obtained by drawing the best straight line through the points and finding the equation of this line. This is simpler than the usual direct method of obtaining the equation. On the other hand, when the

TABLE II.—THE MOST SUITABLE TYPES OF EQUATIONS FOR THE MINE CHARACTERISTIC.

No.	Name of colliery.	Period of year.	Mean temperature of external air, in degs. Fahr.	Types of equations.			Degree of agreement of $p = \rho Q^2 - K$ with observed data.
				$p = AQ^2 + BQ - C.$	$p = \rho Q^n - C.$	$p = \rho Q^2 - K.$	
1	Arniston	Winter	41·27	$p=2·81Q^2+0·88Q-3·16$	$p=3·57Q^{1·86}-3·16$	$p=2·98Q^2-2·10$	Good
		Spring	48·63	$p=1·44Q^2+8·02Q-7·62$	$p=9·30Q^{1·22}-7·62$	$p=3·99Q^2-1·75$	Good
		Summer	57·93	$p=1·56Q^2+6·65Q-5·61$	$p=8·31Q^{1·22}-5·61$	$p=4·00Q^2-1·36$	Fair
2	Easthouses	Winter	35·03	$p=1·85Q^2+4·09Q-4·19$	$p=5·92Q^{1·34}-4·19$	$p=3·70Q^2-1·93$	Fair
		Spring	51·17	$p=2·00Q^2+2·10Q-1·41$	$p=4·14Q^{1·46}-1·41$	$p=3·25Q^2-0·58$	Very good
		Summer	57·70	$p=3·50Q^2+2·10Q-1·12$	$p=5·60Q^{1·91}-1·12$	$p=4·80Q^2-0·30$	Good
3	Polkemmet	Winter	46·64	$p=0·42Q^2+10·92Q-11·90$	$p=11·35Q^{1·05}-11·90$	$p=4·20Q^2-4·20$	Very good
		Spring	57·79	$p=1·56Q^2+6·50Q-8·15$	$p=8·02Q^{1·26}-8·15$	$p=3·68Q^2-3·24$	Very good
4	Prestonlinks	Winter	39·95	$p=1·20Q^2+4·80Q-4·10$	$p=5·94Q^{1·28}-4·10$	$p=2·80Q^2-0·90$	Good
		Spring	44·92	$p=1·25Q^2+4·50Q-5·10$	$p=5·67Q^{1·33}-5·10$	$p=2·32Q^2-0·78$	Good
		Summer	65·50	$p=1·40Q^2+4·90Q-3·00$	$p=6·32Q^{1·28}-3·00$	$p=3·22Q^2-0·00$	Good
5	Dunnikier	Winter	37·90	$p=3·44Q^2+0·83Q-0·73$	$p=4·36Q^{1·78}-0·73$	$p=3·88Q^2-0·38$	Very good
		Spring	46·85	$p=1·88Q^2+5·87Q-3·55$	$p=7·73Q^{1·27}-3·55$	$p=4·53Q^2-0·42$	Very good
		Summer	60·65	$p=3·44Q^2+0·87Q-0·41$	$p=4·36Q^{1·78}-0·41$	$p=3·88Q^2-0·02$	Very good

TABLE II. (*Continued*).—THE MOST SUITABLE TYPES OF EQUATIONS FOR THE MINE CHARACTERISTIC.

No.	Name of colliery.	Period of year.	Mean temperature of external air, in degs. Fahr.	Types of equations. $p = AQ^2 + BQ - C$.	$p = \rho Q^n - C$.	$p = \rho Q^2 - K$.	Degree of agreement of $p = \rho Q^2 - K$ with observed data.
6	Kinglassie	Winter	40·70	$p=7{\cdot}16Q^2+0{\cdot}50Q-0{\cdot}66$	$p=7{\cdot}66Q^{1{\cdot}94}-0{\cdot}66$	$p=7{\cdot}41Q^2-0{\cdot}47$	Very good
		Spring	44·98	$p=7{\cdot}03Q^2-0{\cdot}06Q-0{\cdot}25$	$p=7{\cdot}06Q^{1{\cdot}94}-0{\cdot}25$	$p=7{\cdot}08Q^2-0{\cdot}37$	Good
		Summer	58·75	$p=5{\cdot}31Q^2+2{\cdot}18Q-0{\cdot}07$	$p=7{\cdot}55Q^{1{\cdot}68}-0{\cdot}07$	$p=6{\cdot}53Q^2+0{\cdot}85$	Good for large quantities; very poor for small quantities
7	Valleyfield	Winter	33·64	$p=2{\cdot}80Q^2+1{\cdot}04Q-4{\cdot}08$	$p=3{\cdot}68Q^{1{\cdot}86}-4{\cdot}08$	$p=2{\cdot}95Q^2-2{\cdot}94$	Fair
		Spring	49·80	$p=1{\cdot}60Q^2+4{\cdot}20Q-4{\cdot}90$	$p=5{\cdot}31Q^{1{\cdot}48}-4{\cdot}90$	$p=2{\cdot}63Q^2-1{\cdot}02$	Fair
		Summer	63·25	$p=2{\cdot}00Q^2+2{\cdot}14Q-1{\cdot}91$	$p=3{\cdot}83Q^{1{\cdot}68}-1{\cdot}91$	$p=2{\cdot}57Q^2-0{\cdot}09$	Very good
8	Wellesley	Winter	35·75	$p=4{\cdot}60Q^2+3{\cdot}28Q-5{\cdot}06$	$p=7{\cdot}74Q^{1{\cdot}69}-5{\cdot}06$	$p=5{\cdot}45Q^2-2{\cdot}00$	Very good
		Spring	44·26	$p=5{\cdot}00Q^2+0{\cdot}07Q-2{\cdot}32$	$p=5{\cdot}09Q^{1{\cdot}996}-2{\cdot}32$	$p=4{\cdot}67Q^2-1{\cdot}50$	Very good
		Summer	65·00	$p=4{\cdot}50Q^2+2{\cdot}15Q-1{\cdot}71$	$p=6{\cdot}63Q^{1{\cdot}76}-1{\cdot}71$	$p=5{\cdot}25Q^2-0{\cdot}25$	Very good
9	Hylton	Winter	35·40	$p=2{\cdot}55Q^2+0{\cdot}06Q-5{\cdot}83$	$p=2{\cdot}60Q^{1{\cdot}99}-5{\cdot}83$	$p=2{\cdot}44Q^2-5{\cdot}16$	Fair
10	Silksworth	Winter	36·16	$p=2{\cdot}19Q^2+7{\cdot}75Q-15{\cdot}00$	$p=9{\cdot}16Q^{1{\cdot}41}-15{\cdot}00$	$p=3{\cdot}91Q^2-6{\cdot}80$	Fair
11	Coventry	Winter	41·30	$p=12{\cdot}00Q^2+11{\cdot}60Q-12{\cdot}40$	$p=23{\cdot}83Q^{1{\cdot}50}-12{\cdot}40$	$p=18{\cdot}50Q^2-7{\cdot}44$	Fair
12	Craven	Winter	37·23	$p=7{\cdot}50Q^2+16{\cdot}25Q-6{\cdot}55$	$p=10{\cdot}00Q^{1{\cdot}20}-6{\cdot}55$	$p=21{\cdot}00Q^2-1{\cdot}60$	Fair
13	East Ardsley	Winter	54·86	$p=1{\cdot}88Q^2+6{\cdot}11Q-4{\cdot}49$	$p=7{\cdot}91Q^{1{\cdot}31}-4{\cdot}49$	$p=4{\cdot}20Q^2-0{\cdot}55$	Very good
14	Lodna ...	Winter	80·00 (shade)	$p=2{\cdot}08Q^2+0{\cdot}64Q-0{\cdot}44$	$p=2{\cdot}74Q^{1{\cdot}7}-{}^{5}0{\cdot}44$	$p=2{\cdot}50Q^2-0{\cdot}23$	Very good

equation has been found directly, this artifice provides a very useful check. In Figures 36-47, the straight lines are those corresponding to the equations found directly, i.e. the figures are checks of the accuracy of the equations given in Table 2.

It is thought that three of the types of equations are worthy of further mention. In Table 2, there are collected the suitable equations of those types for the upper or principal parts of the curves (Figures 23-34). To these are added those of the East Ardsley Colliery, Yorkshire, and the Lodna Colliery, India. East Ardsley Colliery works three seams, of inclinations varying from 1 in 24 to 1 in 55, from shafts 654 feet and 594 feet deep, and is ventilated by a double-inlet "Leeds" suction fan, normally producing about 100,000 cubic feet of air per minute. The observations were made under Dr. J. N. Williamson for winter conditions. In the Indian case, the measurements were made in March 1925 by Dr. D. Penman and Mr. T. A. Wetherell: three seams of coal, 27, 7 and 27 feet thick respectively are being worked, and the colliery is ventilated by a double-inlet Turbon suction fan, capable of producing 100,000 cubic feet of air per minute with a water-gauge reading of 1.25 inches.

<u>The Resistance of a Mine.</u> - J. J. Atkinson[1] himself was the first to put forward the suggestion that an expression such as $p = R Q^2$ could be substituted

[1] "The Theory of Mine Ventilation", Trans. N. E. Inst. 1854-1855, vol. 111, p. 73

for the well-known Atkinson formula. To use this coefficient R as a measure of the resistance of a mine was never suggested until 1891, when Professor A.Rateau[1] read his paper "Théorie des Turbo Machines," in which he gave $\frac{H}{Q^2}$ as the measure of the resistance of the circuit, H being the ventilating pressure in metres of air column, and Q, the volume of air circulating in cubic metres per second. In 1892, however, an alternative, preferred by him, was given in the form of $g\frac{H}{Q^2}$; the unit of resistance so derived was to be called a "guibal". Another unit was later used in France and Belgium, namely the "murgue"; in murgues, the resistance $R = \frac{1{,}000\ h}{Q^2}$, where h = millimetres of water column,

and Q = cubic metres per second.

In this country, this matter received little or no consideration until a later date, in fact, until Dr.D.Penman's paper of 1921 (See Penman's Work). His unit was championed by the Institution Committee on "The Theory of Mine Ventilation", and in July 1925 this body defined the unit of resistance, which it called the "Atkinson" (See Hay's Work). Since then this unit has been the subject of much discussion, culminating in a wide-spread appreciation of its advantages, for example, its simplicity of conception, its similitude to an already well-known law - Ohm's Law, the ease with which it can be used in certain

[1]Théorie des Turbo Machines", Comptes Ren.Acad. Sciences, 1891, vol.CX11, p.638.

calculations, and the natural desire for a direct unit of resistance in place of the equivalent orifice theory.

As just stated, the expression $p = R\,Q^2$ can be likened to Ohm's Law, whereby the resistance of an electrical circuit can be measured precisely. With individual lengths of mine air-ways or galleries, $p = R\,Q^2$ very nearly applies except for low air velocities (See Hay's Work), and we have a near approach to the simplicity of the electrical problem. Difficulty arises however when we consider mines as a whole, if we again assume that the resistance can be represented by a single numeral. This assumption has been made by all previous writers on the subject.

We have seen in the curves (Figures 23-34), however, that the two most exact types of equations for the mine characteristic curve are $p = A\,Q^2 + B\,Q - C$ and $p = \rho\,Q^n - C$: each of these contains three interdependent numerals, namely A, B and C in the former case, and ρ, n and C in the latter, no one of which alone can be any criterion of the mine resistance. An additional complication is added in that the <u>total</u> ventilating pressure (i.e. fan-drift pressure plus natural ventilating pressure) should be used in any formula, as it is this pressure which causes the flow of air, that is, our formulae mentioned above become $P = A_1\,Q^2 + B_1\,Q - C_1$ and $P = \rho_1\,Q^n - C_1$. There is therefore the difficulty in all cases of finding the true value of the natural ventilating pressure, which, even if obtained accurately, still leaves the forms of the expressions the same. C_1 will be smaller than C, but seldom will it be zero, so that three numerals still remain, instead of one - the aim is to obtain one only. The "kink" also introduces complication in the form of other coefficients, but it will be sufficient to obtain some criterion of the resistance over the fan's working range.

Hopes are raised to some extent when one considers the form $p = \rho Q^2 - K$. This type, as has been shown, while not very exact, is fairly satisfactory as regards tracing the curve through the observed points; it is also a more convenient form. In certain cases, where the "kink" is not too pronounced, e.g. Prestonlinks Colliery (Figure 26), an equation of this type follows the observed points very closely from the upper extreme to the vertical axis; for this case also, the term K evaluates the natural ventilating pressure fairly accurately (See Section (5)). Even when the "kink" is fairly obvious, this equation satisfies to a reasonable extent, the observed points, with the exception of those in the unstable zone. Its value for the natural ventilating pressure seems fairly satisfactory in those cases as well, (See Section (5)).

It would appear that if the natural ventilating pressure (or, more strictly the α term, see Section(5)) were scaled off on the vertical axis below the origin (or above it, when natural ventilation opposes the fan) a curve of the type $p = R\,Q^2 - K$ could be found to pass through that point (i.e. $K = \alpha$) and also to represent satisfactorily the upper part of the characteristic curve. Within limits then, it would seem that the relation $P = p + \alpha = R\,Q^2$ can be accepted as fairly accurate; or, in words,

The combined ventilating pressure, namely, the sum of the fan-drift pressure and the natural ventilating pressure, in pounds per square foot, is equal to the square of the air-volume, in kilocusecs multiplied by the mine resistance in Atkinsons.

This relation gives a single numeral as the resistance of a mine, and supports the Institution Ventilation Committee's recommendation that $P = R\,Q^2$ be accepted as standard in ascertaining resistance; it must always be remembered and noted that P is the <u>total pressure</u>, not merely the fan drift pressure. Also, although the relation is somewhat approximate, it is probably accurate enough for a problem, involving as this one does, so many variable factors.

The resistance R of a mine, for all practical purposes, should, it seems, be evaluated by first measuring the α term of the natural ventilating pressure preferably by the method used by Murgue at Créal (see Section (5)); by taking the quantity Q and the pressure p in the fan drift at normal fan-speed; and then, by applying the formula, $R = \dfrac{p + \alpha}{Q^2}$.

FIGURE 48.

ARNISTON COLLIERY.

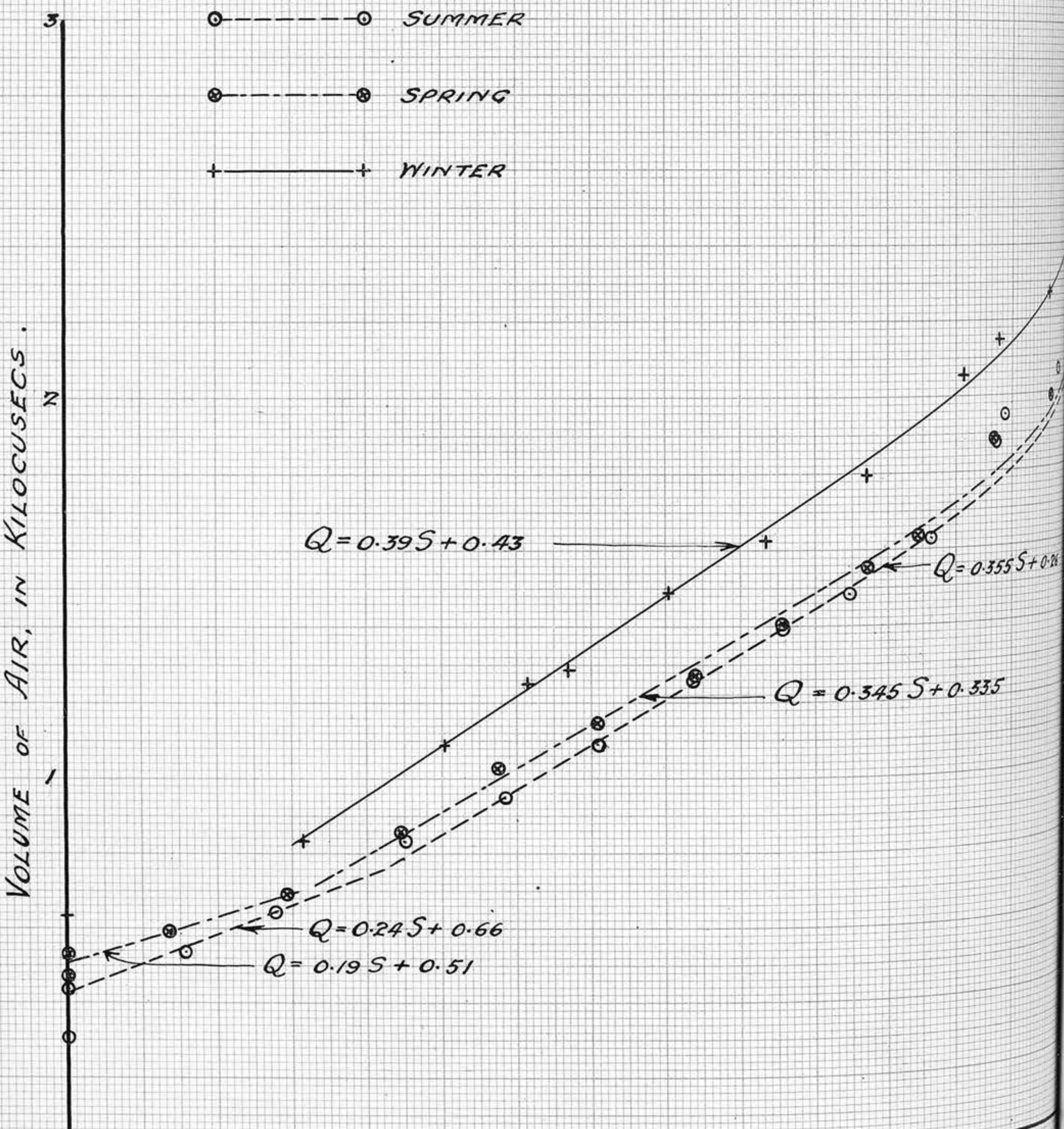


FIGURE 49.

EASTHOUSES COLLIERY.

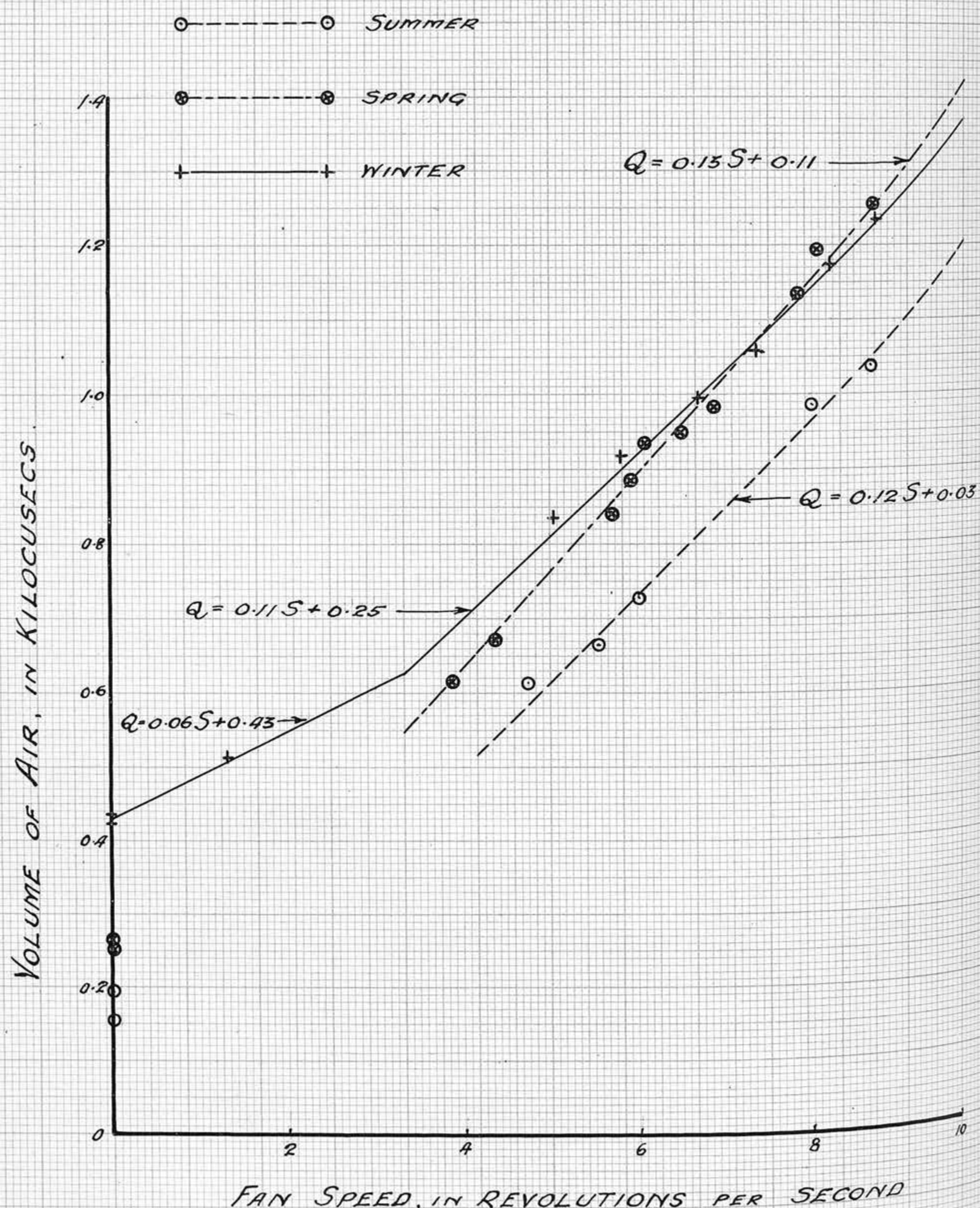
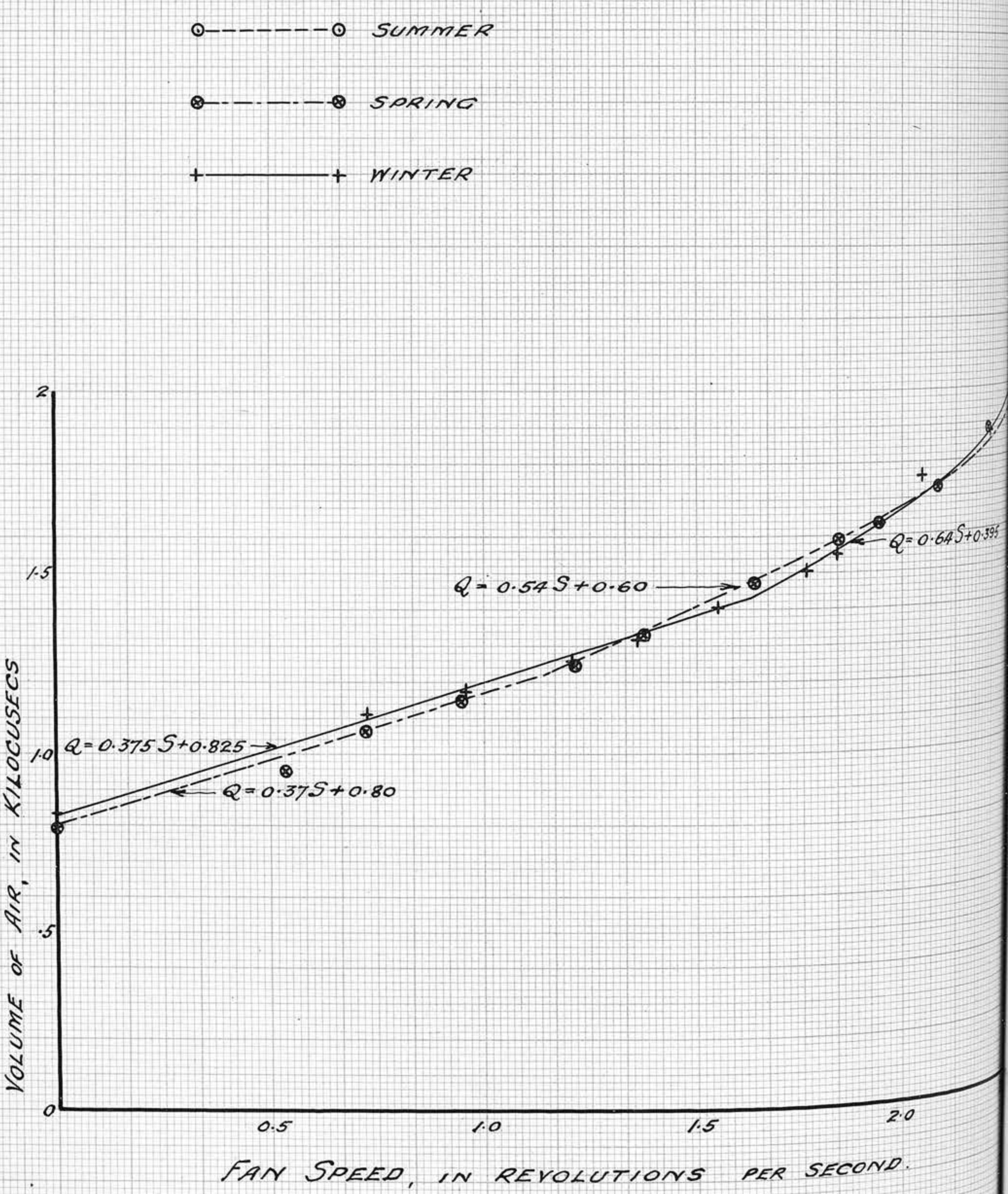


FIGURE 50.

POLKEMMET COLLIERY.



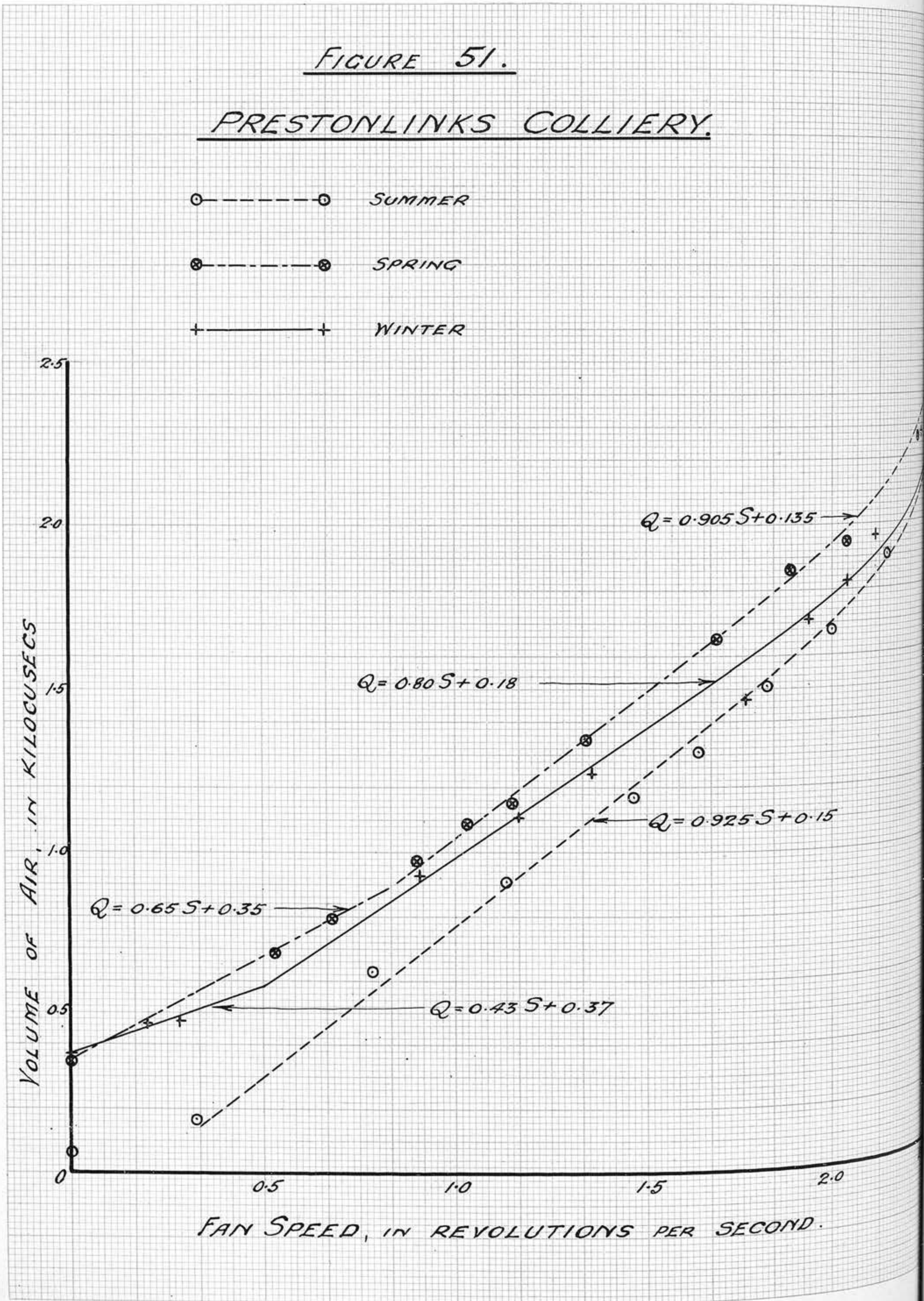
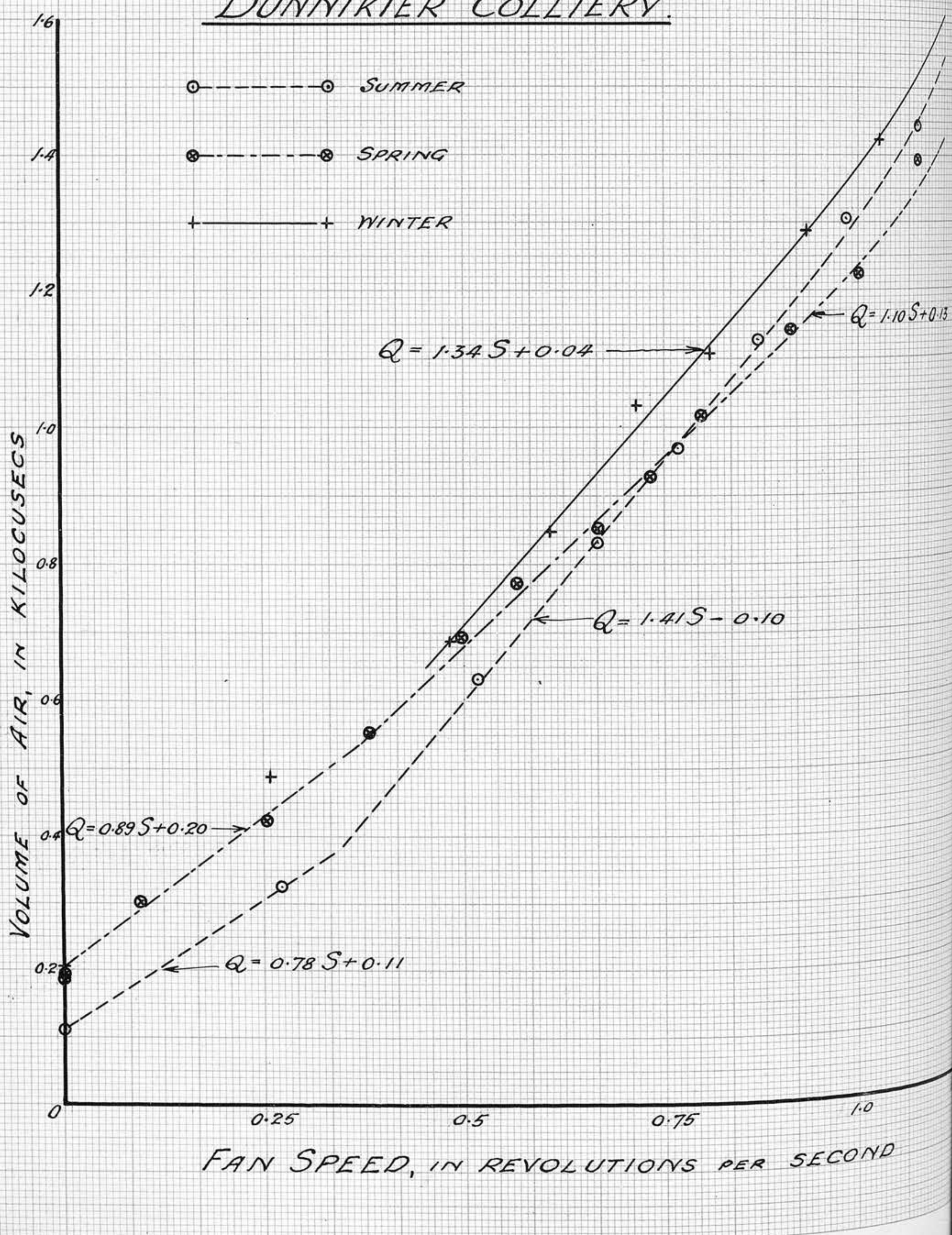


FIGURE 51.
PRESTONLINKS COLLIERY.
SUMMER
SPRING
WINTER
Q = 0·905 S + 0·135
Q = 0·80 S + 0·18
Q = 0·925 S + 0·15
Q = 0·65 S + 0·35
Q = 0·43 S + 0·37
VOLUME OF AIR, IN KILOCUSECS
FAN SPEED, IN REVOLUTIONS PER SECOND.
0
0·5
1·0
1·5
2·0
2·5

FIGURE 52.

DUNNIKIER COLLIERY.



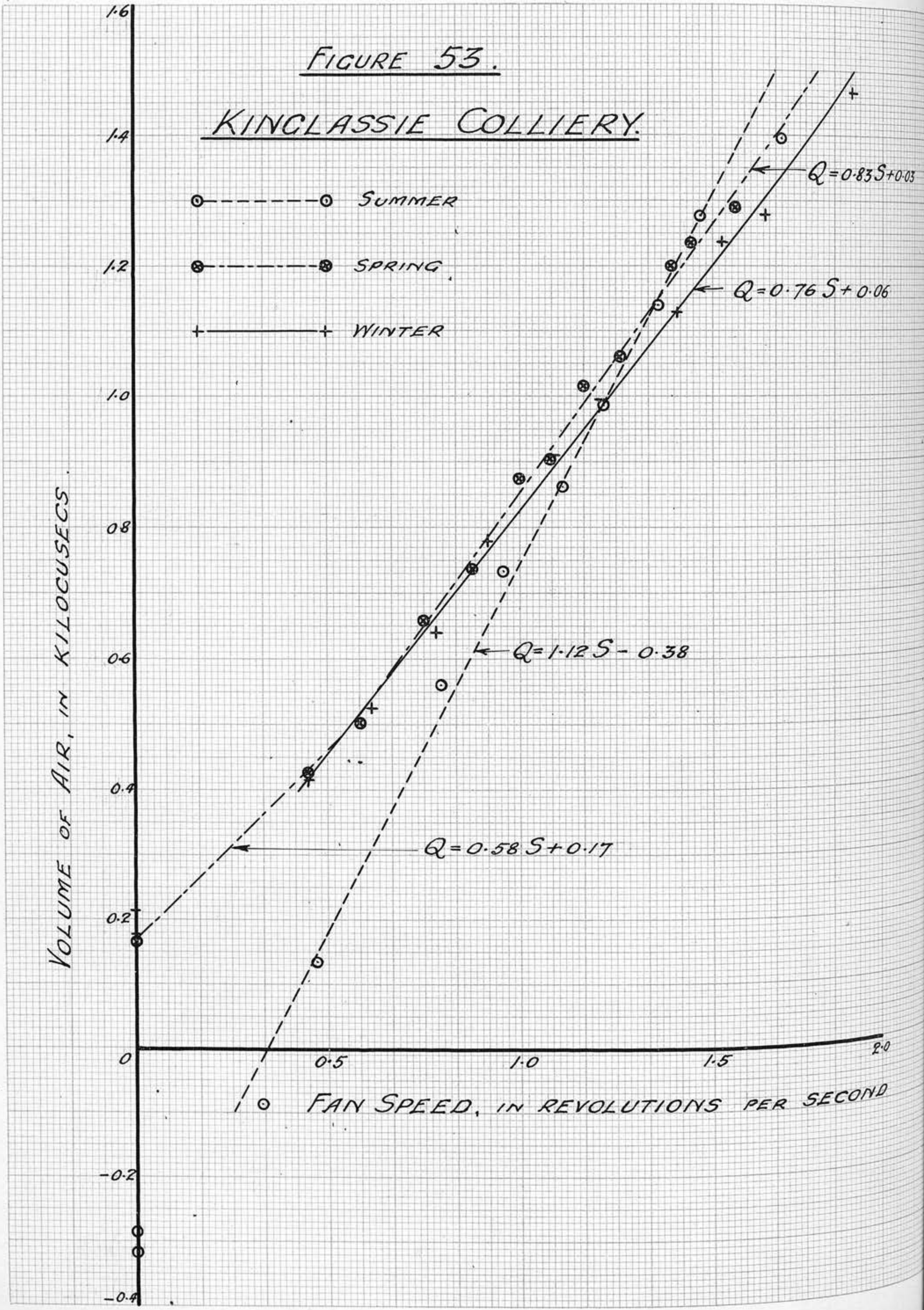


FIGURE 53.
KINCLASSIE COLLIERY.
SUMMER
SPRING
WINTER
Q=0·83 S+0·03
Q=0·76 S+0·06
Q=1·12 S - 0·38
Q=0·58 S+0·17
VOLUME OF AIR, IN KILOCUSECS.
FAN SPEED, IN REVOLUTIONS PER SECOND
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
-0·2
-0·4
0·5
1·0
1·5
2·0

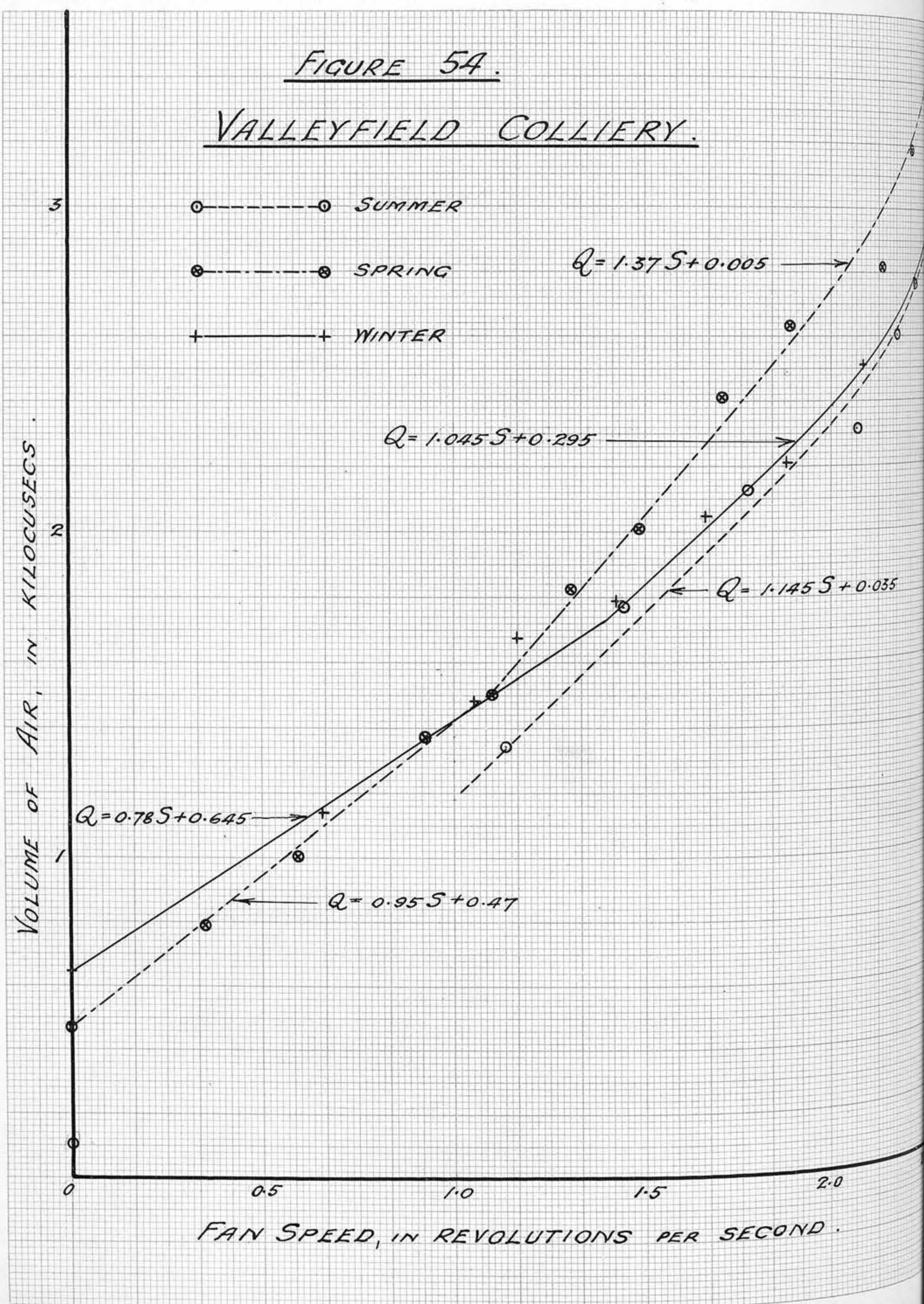


FIGURE 54.
VALLEYFIELD COLLIERY.
SUMMER
SPRING
WINTER
Q = 1·37 S + 0·005
Q = 1·045 S + 0·295
Q = 1·145 S + 0·035
Q = 0·78 S + 0·645
Q = 0·95 S + 0·47
VOLUME OF AIR, IN KILOCUSECS.
FAN SPEED, IN REVOLUTIONS PER SECOND.
0
0·5
1·0
1·5
2·0
1
2
3

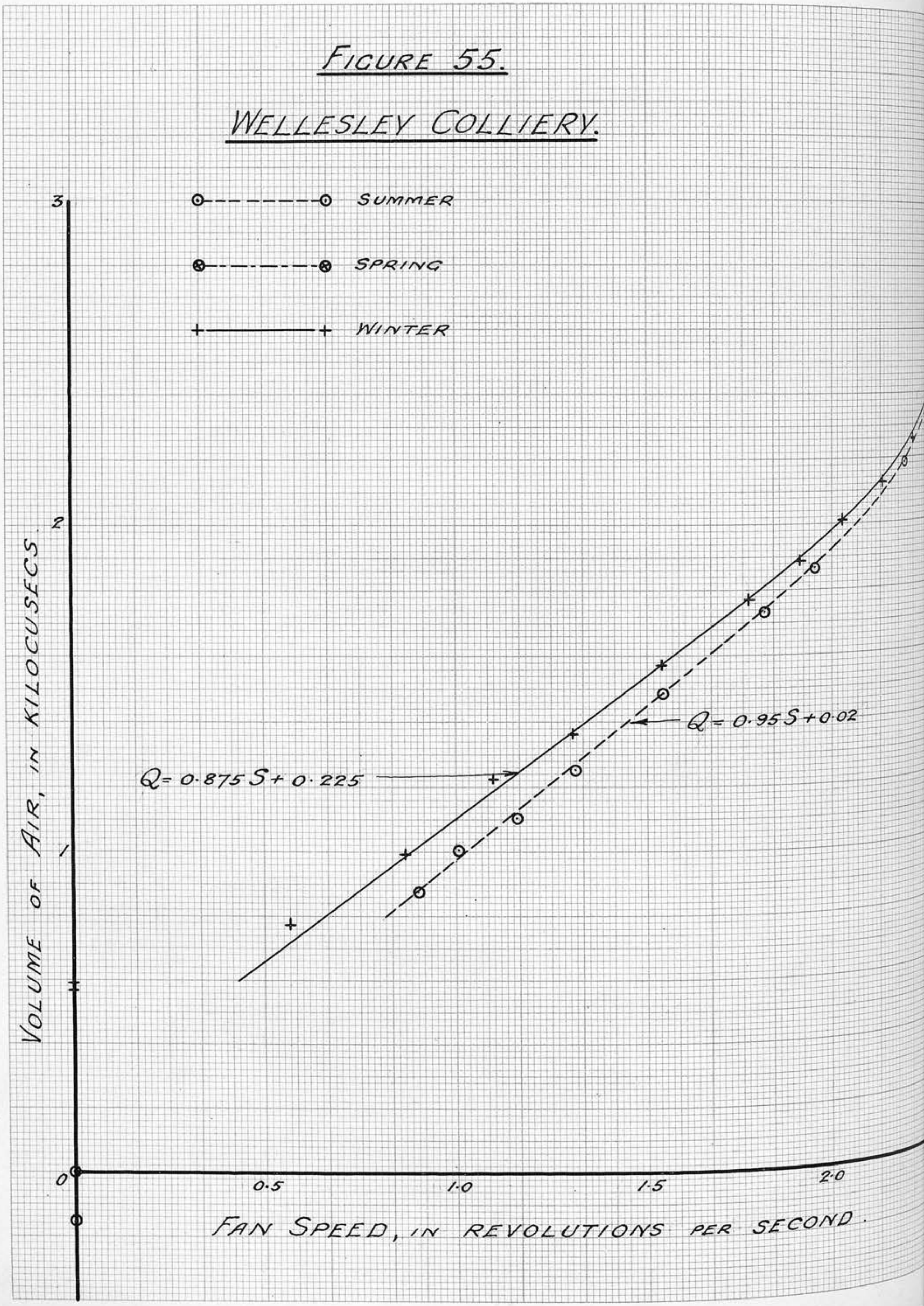
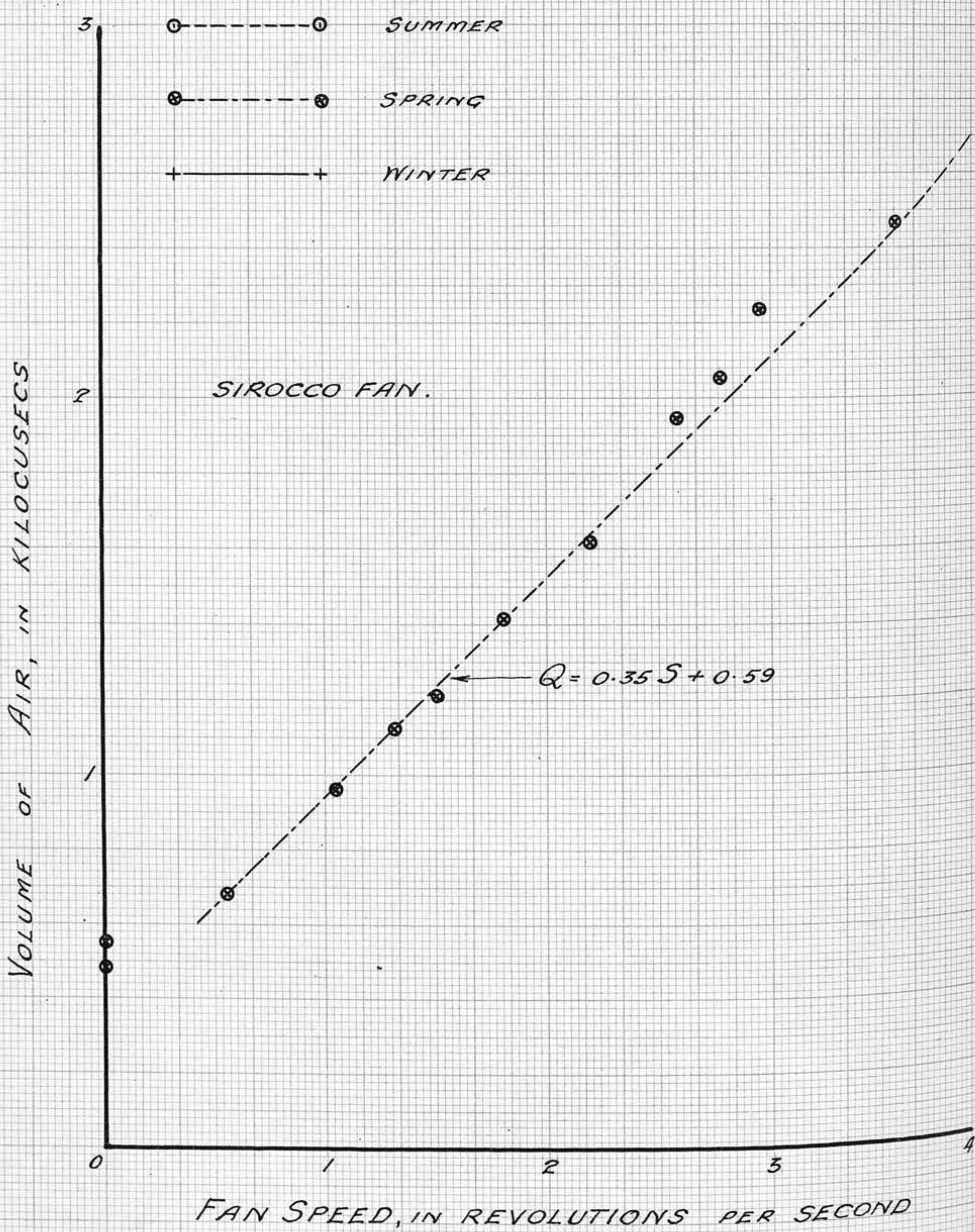


FIGURE 55.
WELLESLEY COLLIERY.
SUMMER
SPRING
WINTER
3
2
1
0
VOLUME OF AIR, IN KILOCUSECS
Q = 0.95 S + 0.02
Q = 0.875 S + 0.225
0.5
1.0
1.5
2.0
FAN SPEED, IN REVOLUTIONS PER SECOND.

FIGURE 55 A.

WELLESLEY COLLIERY.



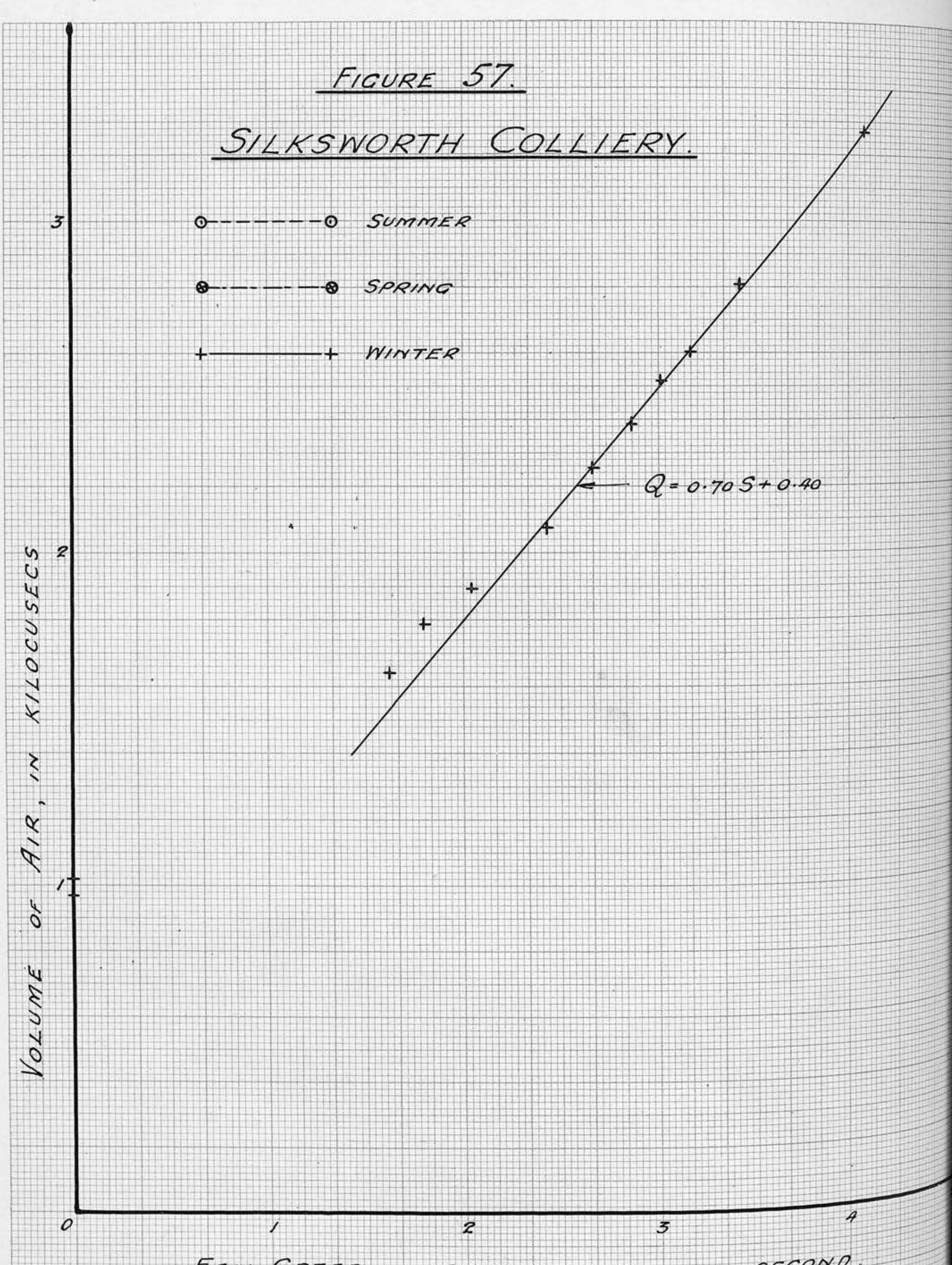


FIGURE 57.
SILKSWORTH COLLIERY.
SUMMER
SPRING
WINTER
Q = 0·70 S + 0·40
VOLUME OF AIR, IN KILOCUSECS
FAN SPEED, IN REVOLUTIONS PER SECOND.
0
1
2
3
4

FIGURE 58.

COVENTRY COLLIERY.

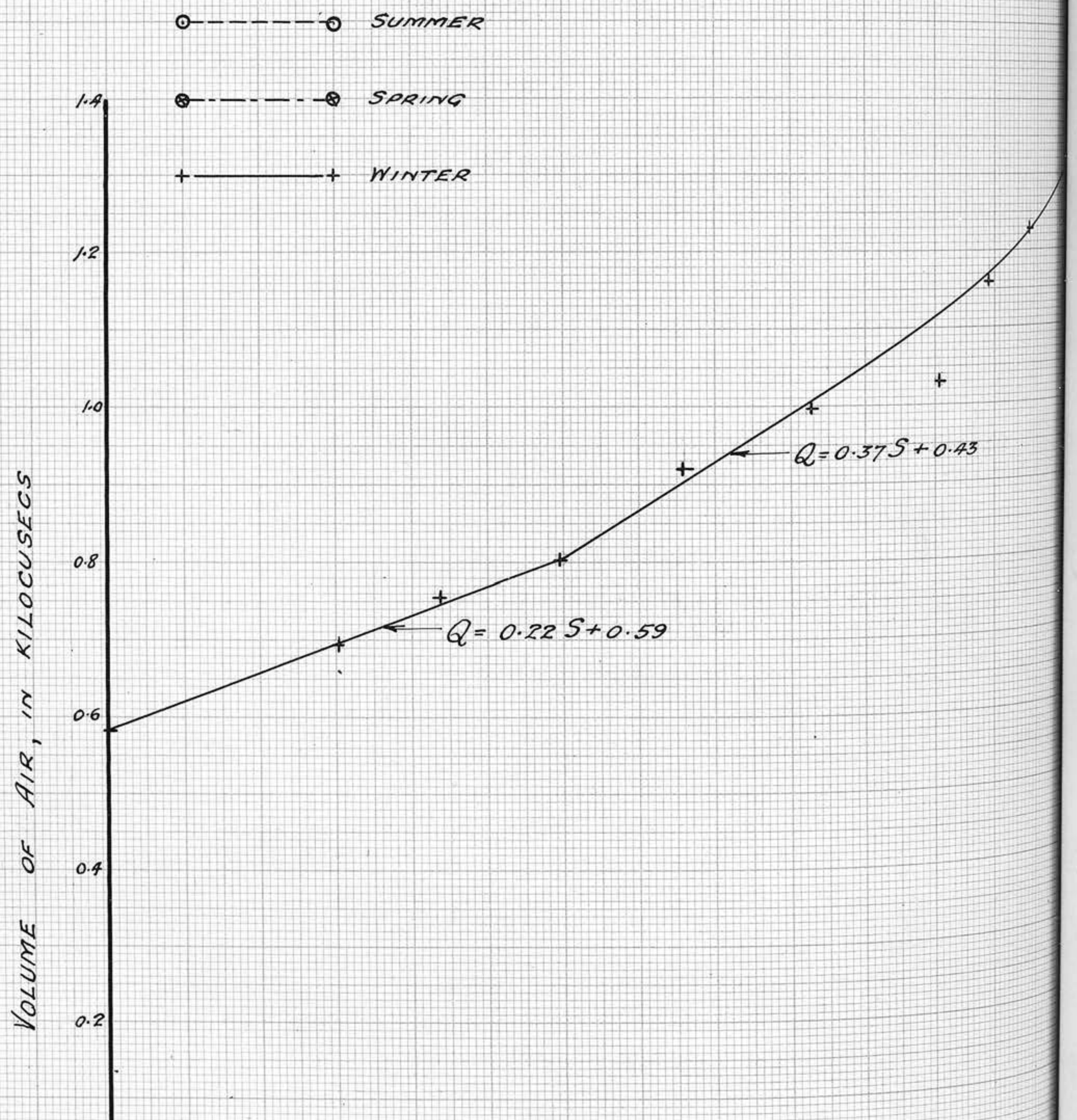
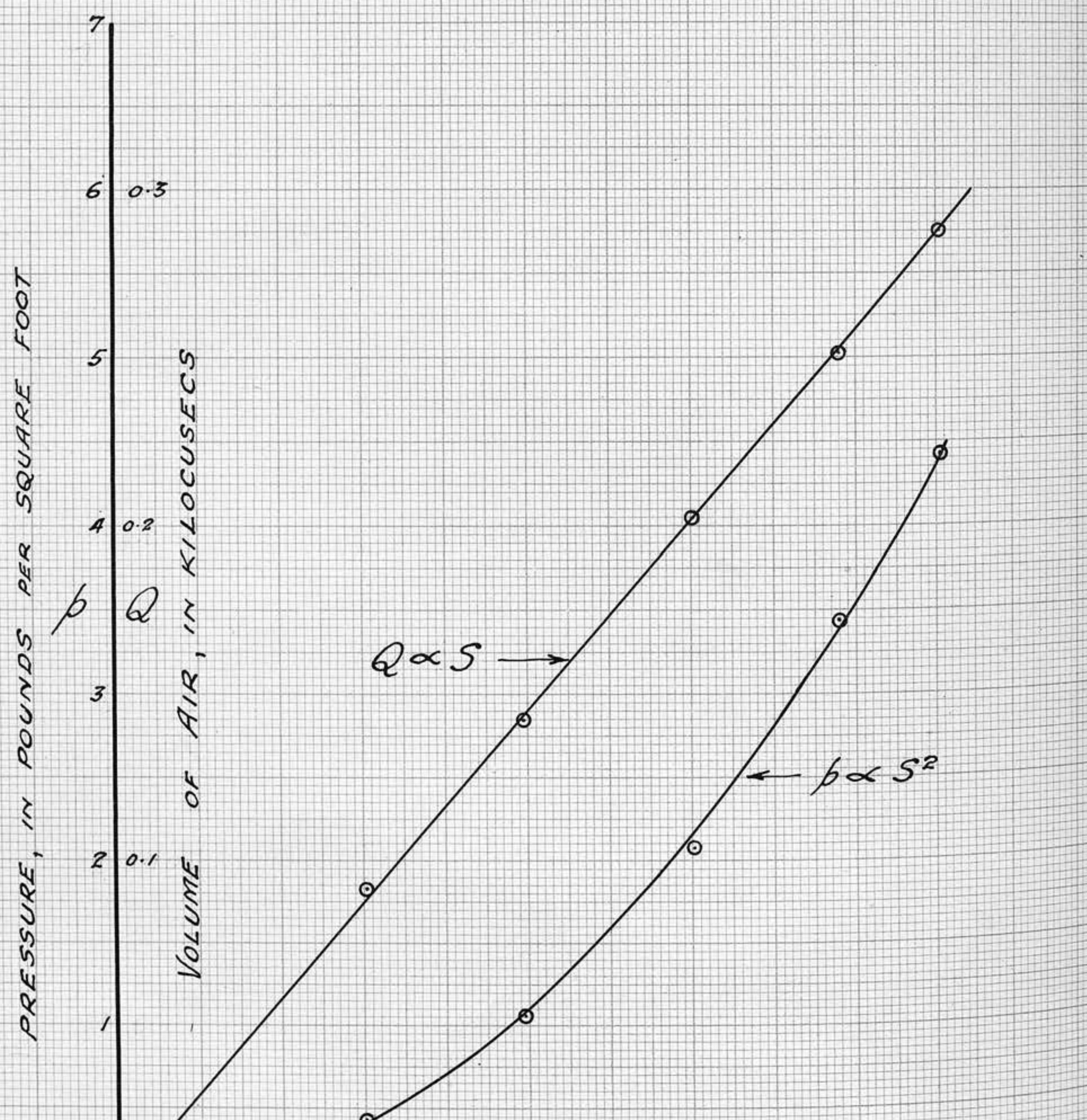


FIGURE 60.



7
6
5
4
3
2
1
0.3
0.2
0.1
PRESSURE, IN POUNDS PER SQUARE FOOT
VOLUME OF AIR, IN KILOCUSECS
p
Q
Q ∝ S
p ∝ S²
0
5
10
15
20
FAN SPEED, IN REVOLUTIONS PER SECOND

TABLE 111. The Most Suitable Type of Equation for the Quantity-Speed Curve.

No.	Name of Colliery.	Period of Year.	Mean temp. of external air in degrees Fahrenheit.	Type of Equation. $Q = F S + G$.	Accuracy of the Equation.
1	Arniston	Winter	41.27	$Q = 0.393S + 0.434$	Fair
		Spring	48.63	$Q = 0.345S + 0.335$	Fair
		Summer	57.93	$Q = 0.355S + 0.260$	Good
2	East-houses	Winter	35.03	$Q = 0.122S + 0.250$	Good
		Spring	51.17	$Q = 0.131S + 0.113$	Fair
		Summer	57.70	$Q = 0.118S + 0.027$	Fair
3	Pol-kemmet	Winter	46.64	$Q = 0.640S + 0.395$	Fair
		Spring	57.79	$Q = 0.538S + 0.602$	Good
4	Preston-links	Winter	39.95	$Q = 0.800S + 0.180$	Fair
		Spring	44.92	$Q = 0.905S + 0.135$	Fair
		Summer	65.50	$Q = 0.925S - 0.150$	Fair
5	Dunni-kier	Winter	37.90	$Q = 1.340S + 0.042$	Good
		Spring	46.85	$Q = 1.104S + 0.133$	Fair
		Summer	60.65	$Q = 1.412S - 0.104$	Good
6	King-lassie	Winter	40.70	$Q = 0.759S + 0.062$	Good
		Spring	44.98	$Q = 0.827S + 0.028$	Good
		Summer	58.75	$Q = 1.002S - 0.239$	Good
7	Valley-field	Winter	33.64	$Q = 1.045S + 0.295$	Fair
		Spring	49.80	$Q = 1.370S + 0.005$	Fair
		Summer	63.25	$Q = 1.145S + 0.035$	Fair
8	Welles-ley	Winter	35.75	$Q = 0.875S + 0.225$	Very Good
		Spring	44.26	$Q = 0.352S + 0.588$	Good
		Summer	65.0	$Q = 0.950S + 0.020$	Good
9	Hylton	Winter	35.40	$Q = 0.520S + 0.885$	Good
10	Silks-worth	Winter	36.16	$Q = 0.700S + 0.400$	Ex.
11	Coventry	Winter	41.30	$Q = 0.374S + 0.432$	Fair
12	Craven	Winter	37.23	$Q = 0.086S + 0.133$	Fair

others, it can be seen quite clearly that there must be a "kink", although there are not enough points at low speeds to shew conclusively that it does exist.

The problem is again a complicated one and the general remarks on the variations in Figures 23-34 again apply. To give a comparison between a drift with no natural ventilating effect and collieries having natural ventilation, a similar graph (Figure 60) is shown for the gallery in the Mining Laboratory, Heriot-Watt College, Edinburgh. In this case, the orthodox relation $Q \propto S$, holds and the equation representing the observed points is that of a straight line passing through the origin.

The Equation of the Quantity-Speed Curves.

After a glance at Figures 48-59, there can be little doubt but that the form of the equation must be that of a straight line. It is also seen that as, due to natural ventilation, the "best straight line" for any of the curves does not pass through the origin, some term is required to denote this. If S denotes the fan-speed, in revolutions per second, an equation $Q = F S + G$ suggests itself, when G represents the effect of natural ventilation and F is a coefficient. This type of equation has been found to satisfy the curves both above and below the " kink". In table 111, are shown the most suitable equations of this type for the upper or working parts of the curves only, as in many cases there are not sufficient points to indicate clearly the "best line" in the lower portion.

The graphs show the suitability of equations of the type $Q = F S + G$ to satisfy the observed points, and the uselessness of the orthodox relation $Q \propto S$ is shown. Further simplification is desirable, but to do this, some method of actually measuring G is required. At Easthouses Colliery, there are readings of the air-volume passing when the upcast incline was open to the external atmosphere. Those values do not by any means equal the values of G in the equations found for the respective periods. It would seem, then, that G is not measured under those circumstances. It is, however, quite futile to be in the least dogmatic on this point, as, apart from having only one isolated case with which to test this suggestion, the colliery has not an independent ventilating system. It seems to the writer more reasonable to expect that G may be obtained by measuring α (See Section (5)) and using this measurement in the equation $P = 0 + \alpha = R Q^2$. A value of Q corresponding to α is thus obtained, and this figure is suggested as being equal to G. It may then be said that $(Q \mp G)$ is proportional to S, the sign being negative when natural ventilation assists the fan and positive when it is against the fan, i.e. the "adjusted air-quantity", $(Q \mp G)$ is proportional to the fan speed. This, however, requires further investigation and is merely a hint, following the previous suggestion, $p + \alpha = RQ^2$. (See Section (1)).

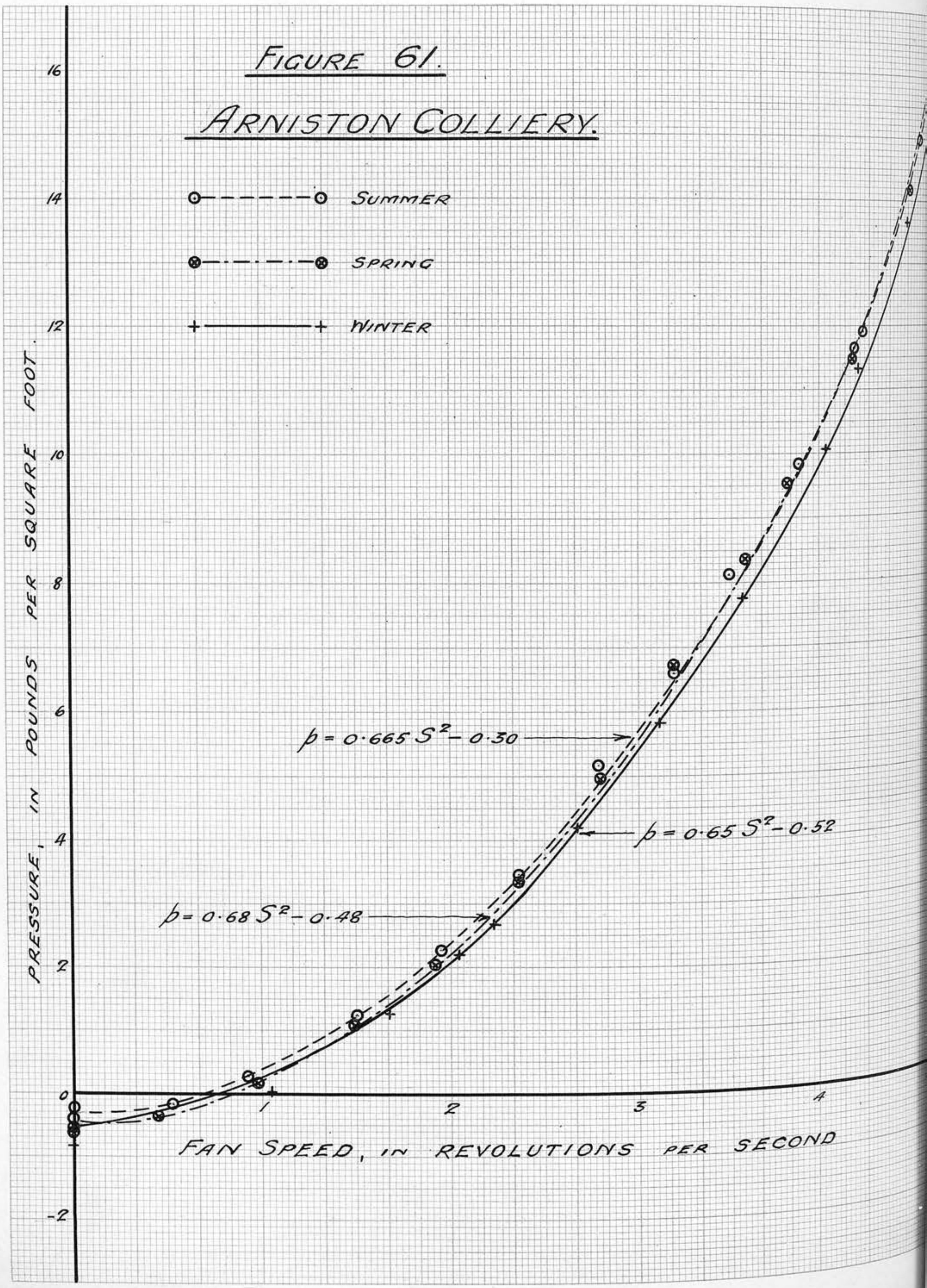


FIGURE 61.
ARNISTON COLLIERY.
SUMMER
SPRING
WINTER
PRESSURE, IN POUNDS PER SQUARE FOOT.
FAN SPEED, IN REVOLUTIONS PER SECOND
p = 0·665 S² − 0·30
p = 0·65 S² − 0·52
p = 0·68 S² − 0·48
16
14
12
10
8
6
4
2
0
-2
1
2
3
4

FIGURE 62.

EASTHOUSES COLLIERY.

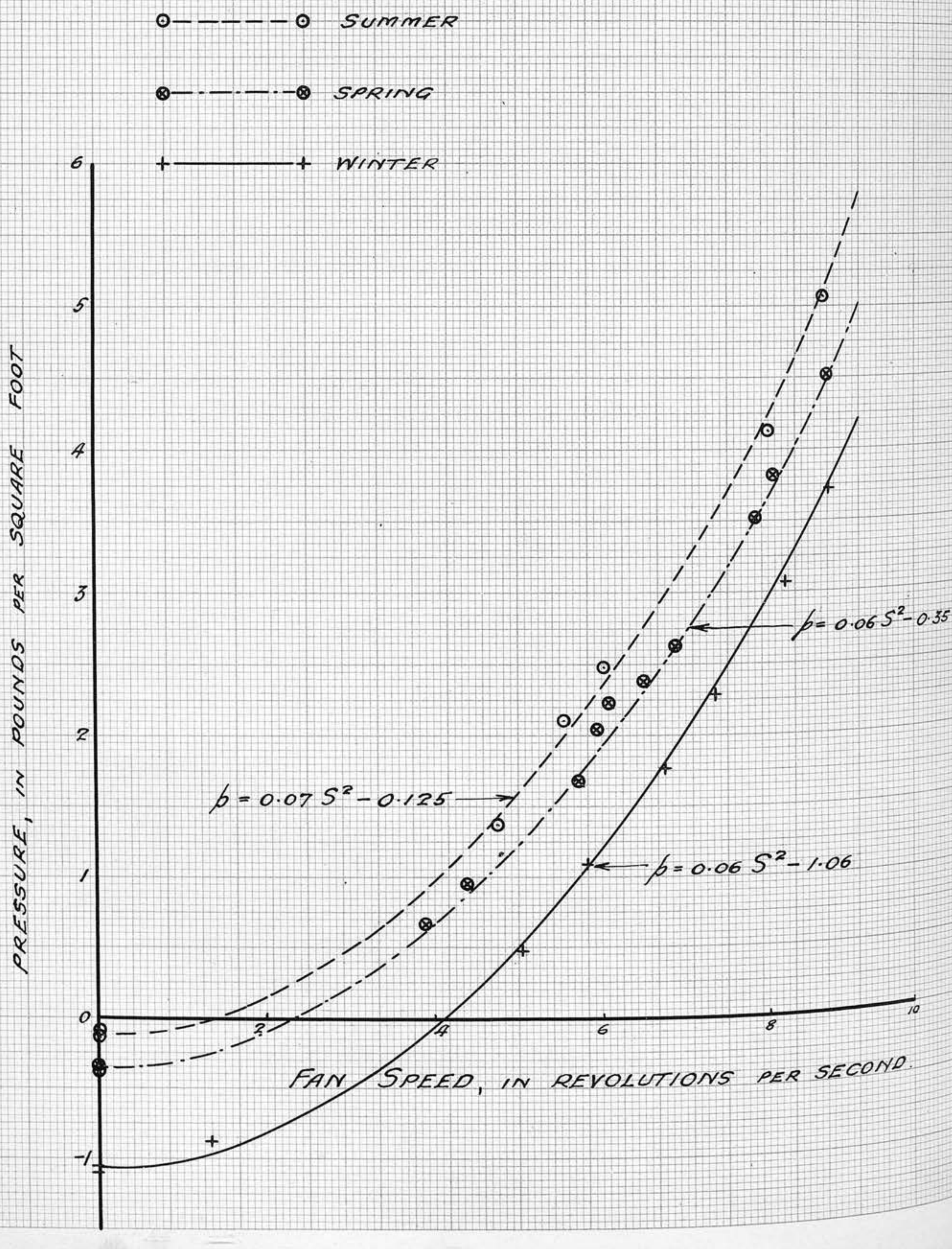
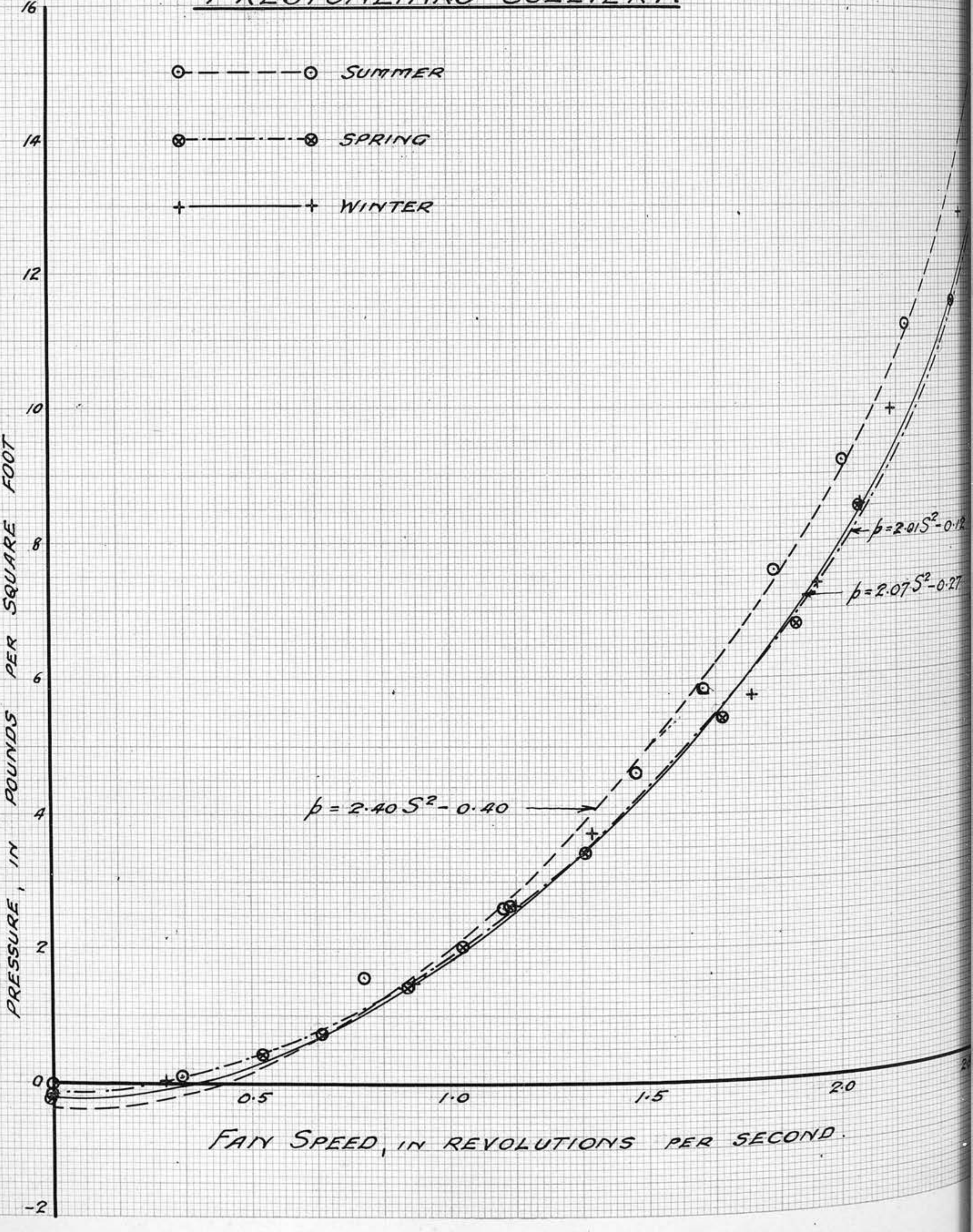


FIGURE 64.

PRESTONLINKS COLLIERY.



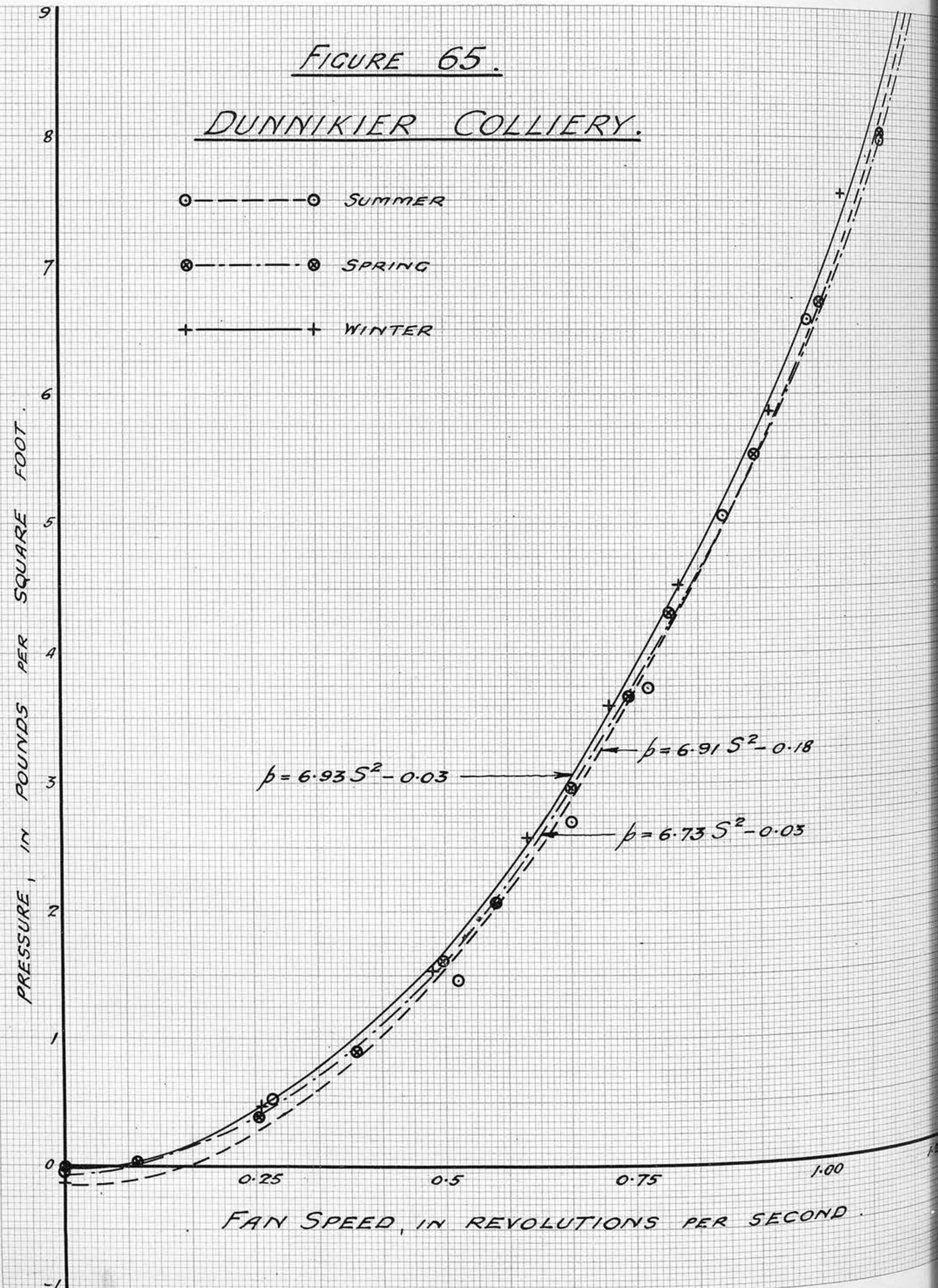


FIGURE 65.
DUNNIKIER COLLIERY.
SUMMER
SPRING
WINTER
p = 6·93 S² − 0·03
p = 6·91 S² − 0·18
p = 6·73 S² − 0·03
PRESSURE, IN POUNDS PER SQUARE FOOT.
FAN SPEED, IN REVOLUTIONS PER SECOND.
9
8
7
6
5
4
3
2
1
0
-1
0·25
0·5
0·75
1·00

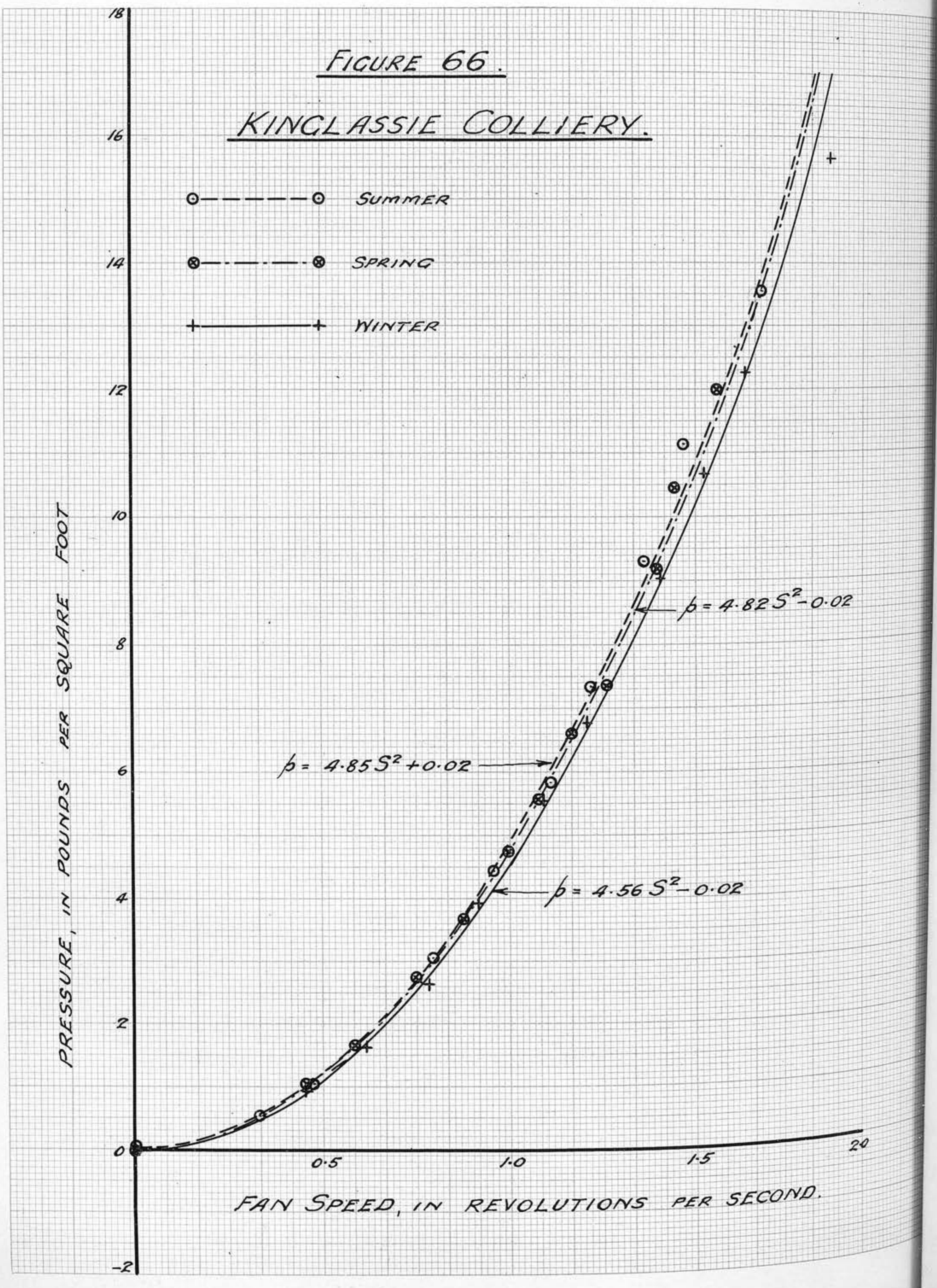


FIGURE 66.
KINGLASSIE COLLIERY.
SUMMER
SPRING
WINTER
$p = 4.82S^2 - 0.02$
$p = 4.85S^2 + 0.02$
$p = 4.56S^2 - 0.02$
PRESSURE, IN POUNDS PER SQUARE FOOT
FAN SPEED, IN REVOLUTIONS PER SECOND.
18
16
14
12
10
8
6
4
2
0
-2
0·5
1·0
1·5
2·0

FIGURE 67.

VALLEYFIELD COLLIERY.

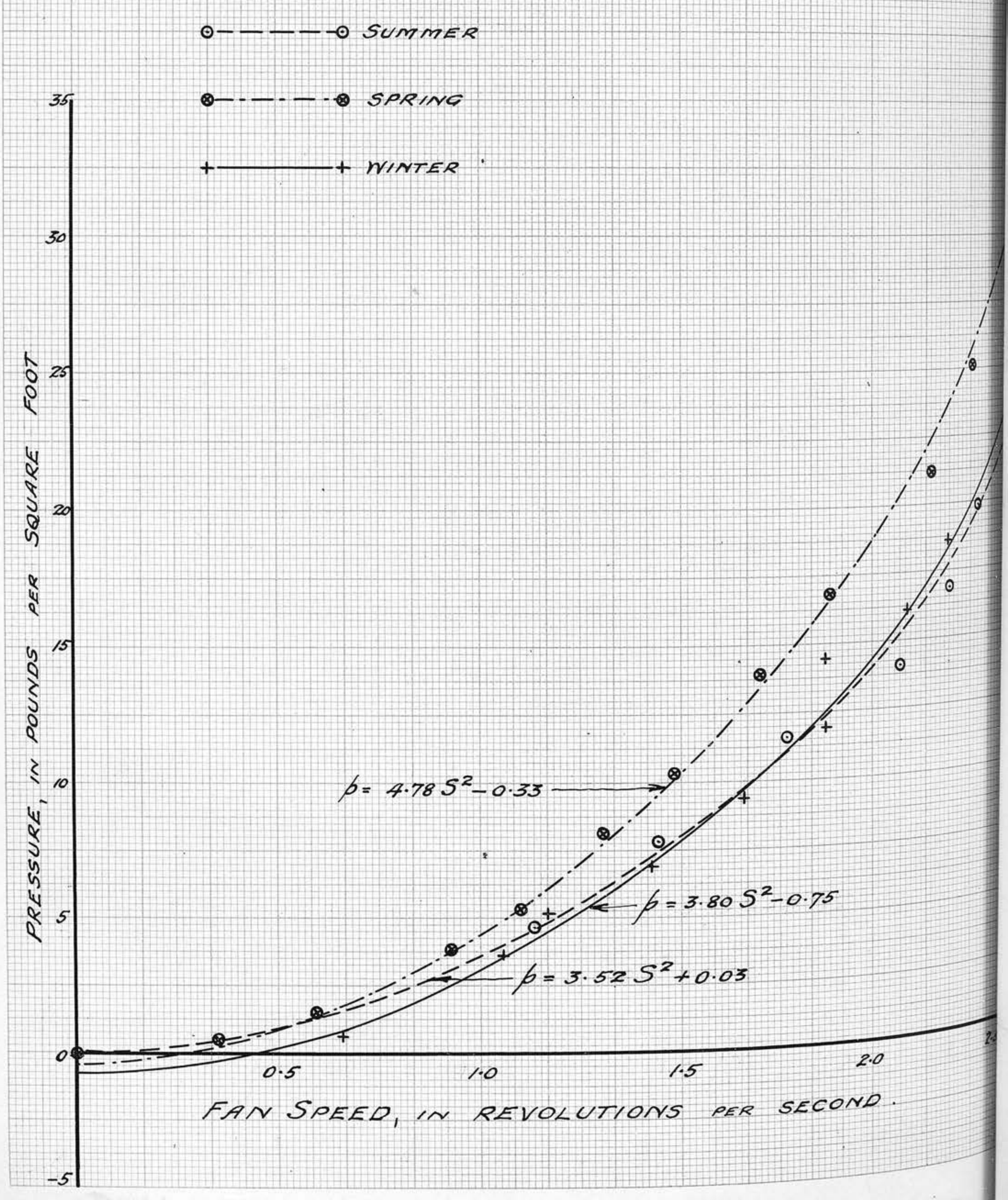
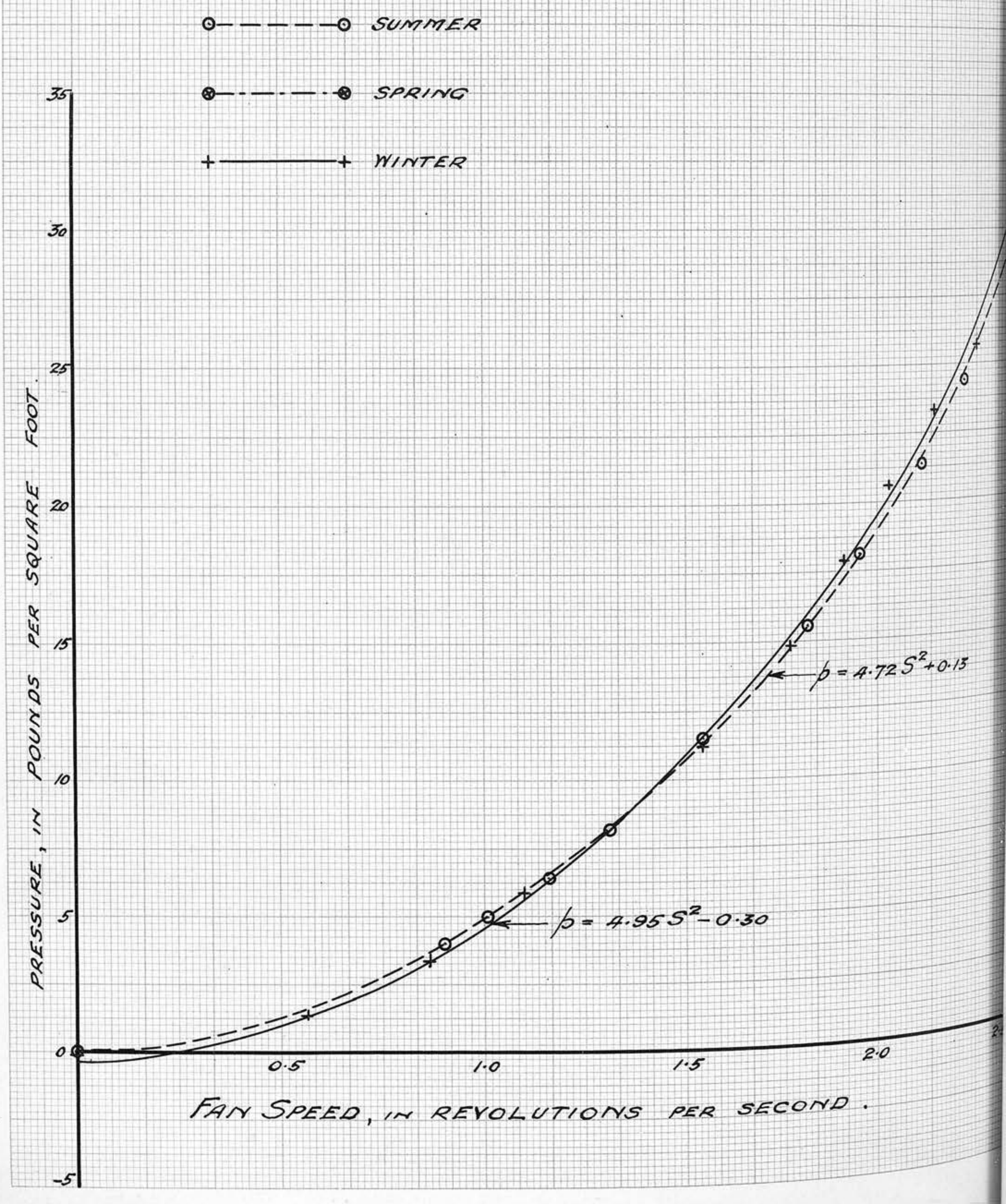


FIGURE 68.

WELLESLEY COLLIERY.



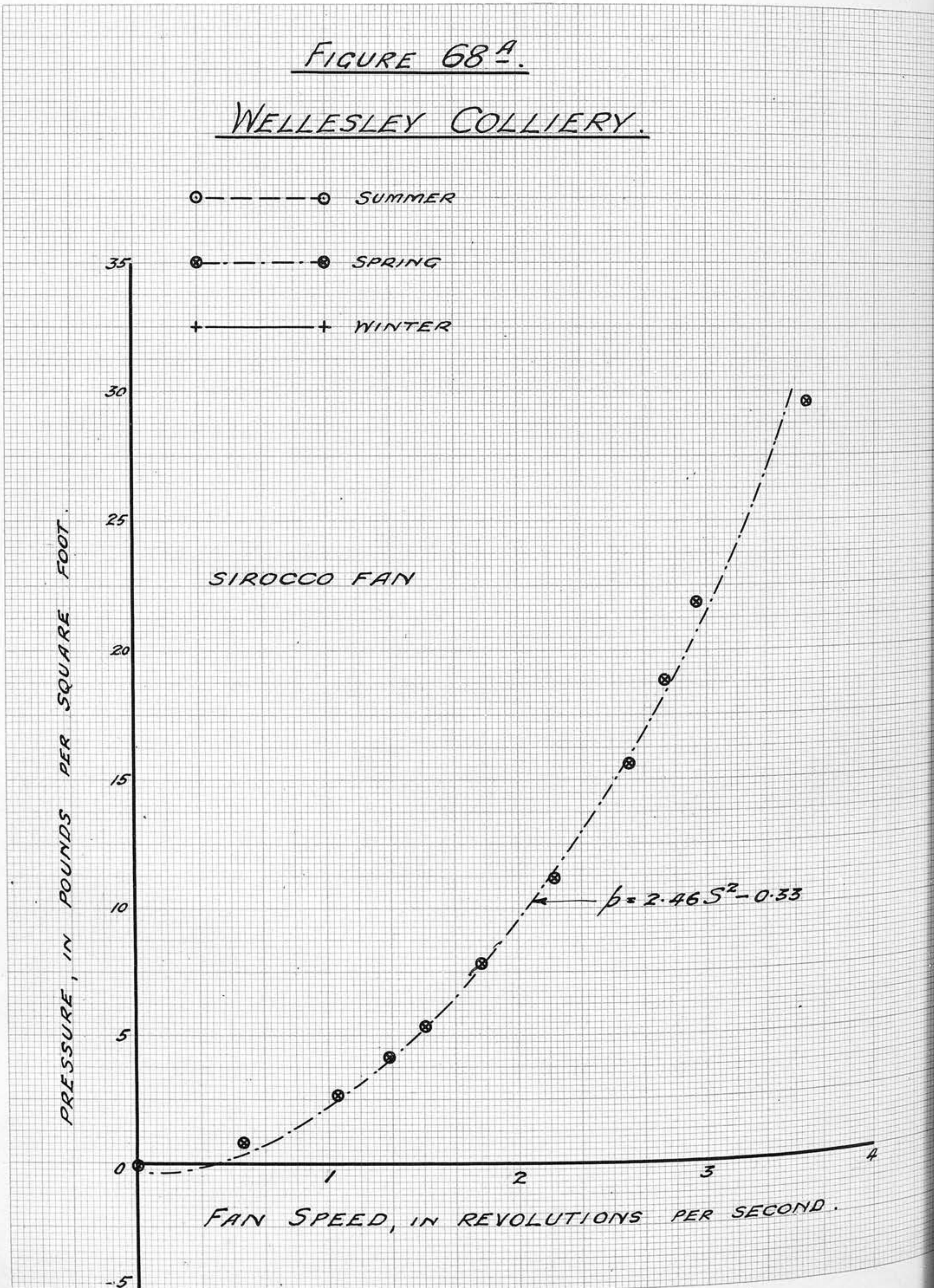


FIGURE 68A.
WELLESLEY COLLIERY.
SUMMER
SPRING
WINTER
SIROCCO FAN
$p = 2 \cdot 46 S^2 - 0 \cdot 33$
PRESSURE, IN POUNDS PER SQUARE FOOT.
FAN SPEED, IN REVOLUTIONS PER SECOND.
35
30
25
20
15
10
5
0
-5
1
2
3
4

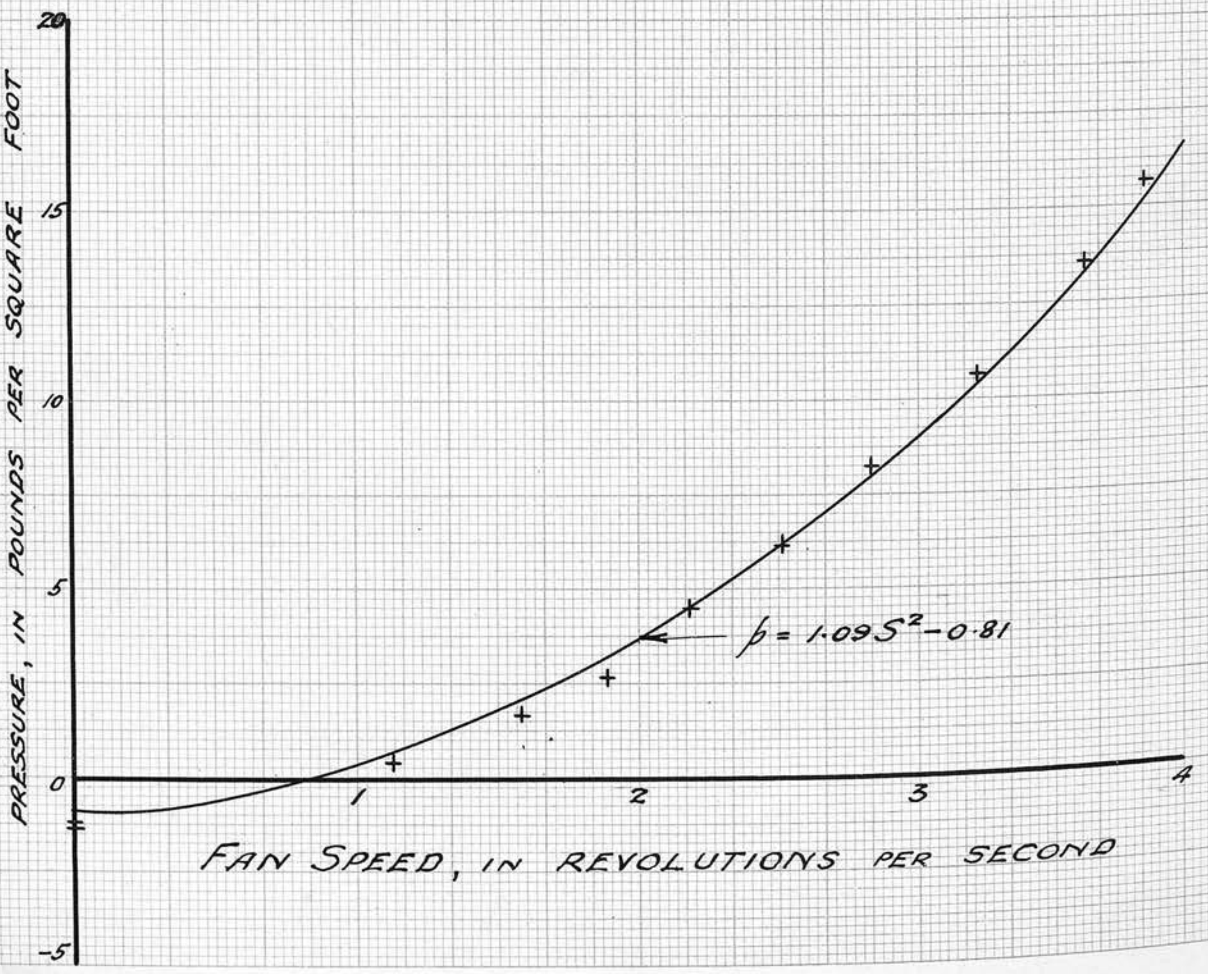
FIGURE 69.

HYLTON COLLIERY.

○- - - - -○ SUMMER

⊗-·-·-·-⊗ SPRING

+———————+ WINTER



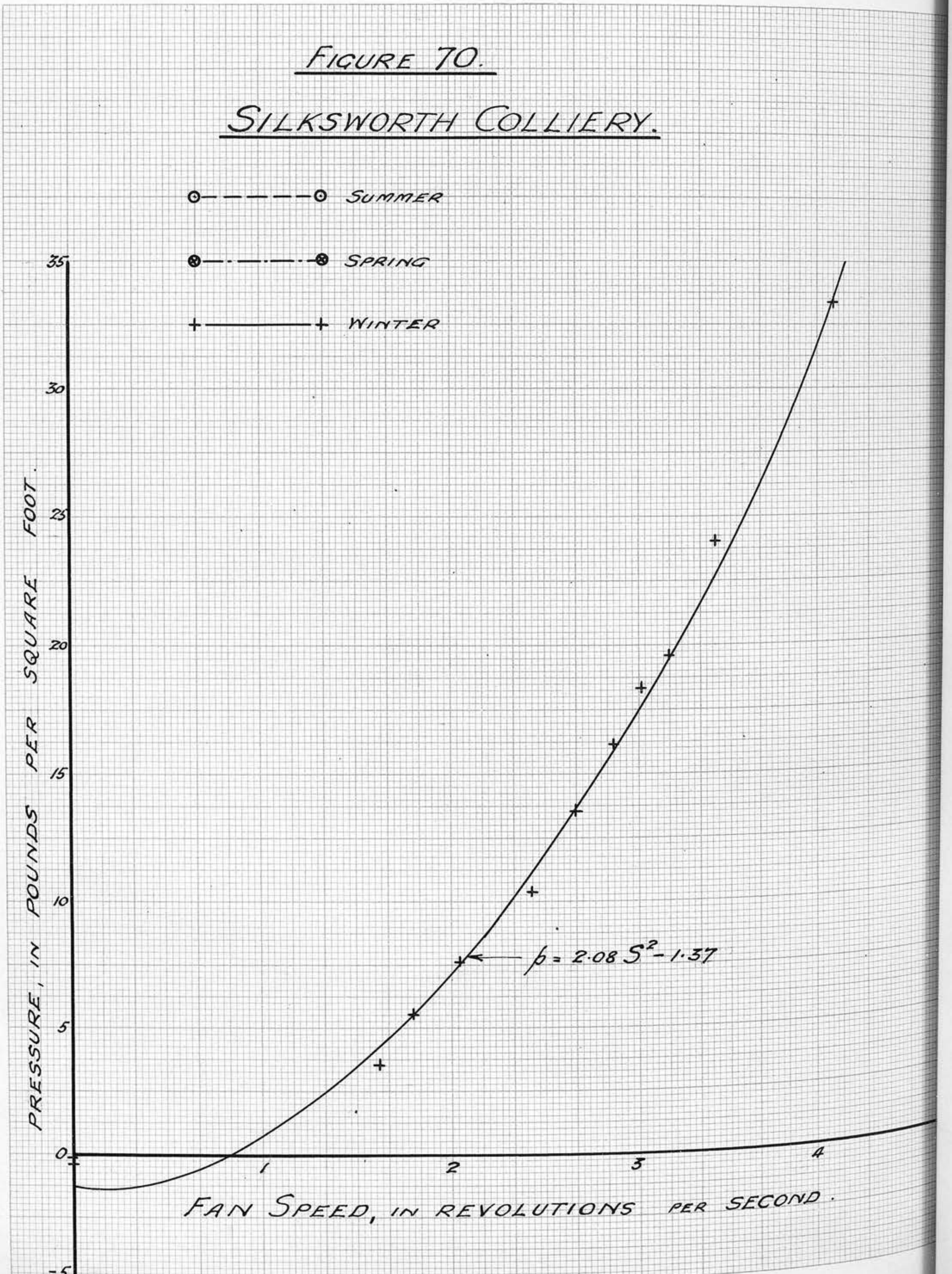


FIGURE 70.
SILKSWORTH COLLIERY.
SUMMER
SPRING
WINTER
$p = 2 \cdot 08\, S^2 - 1 \cdot 37$
PRESSURE, IN POUNDS PER SQUARE FOOT.
FAN SPEED, IN REVOLUTIONS PER SECOND.
35
30
25
20
15
10
5
0
-5
1
2
3
4

FIGURE 71.

COVENTRY COLLIERY.

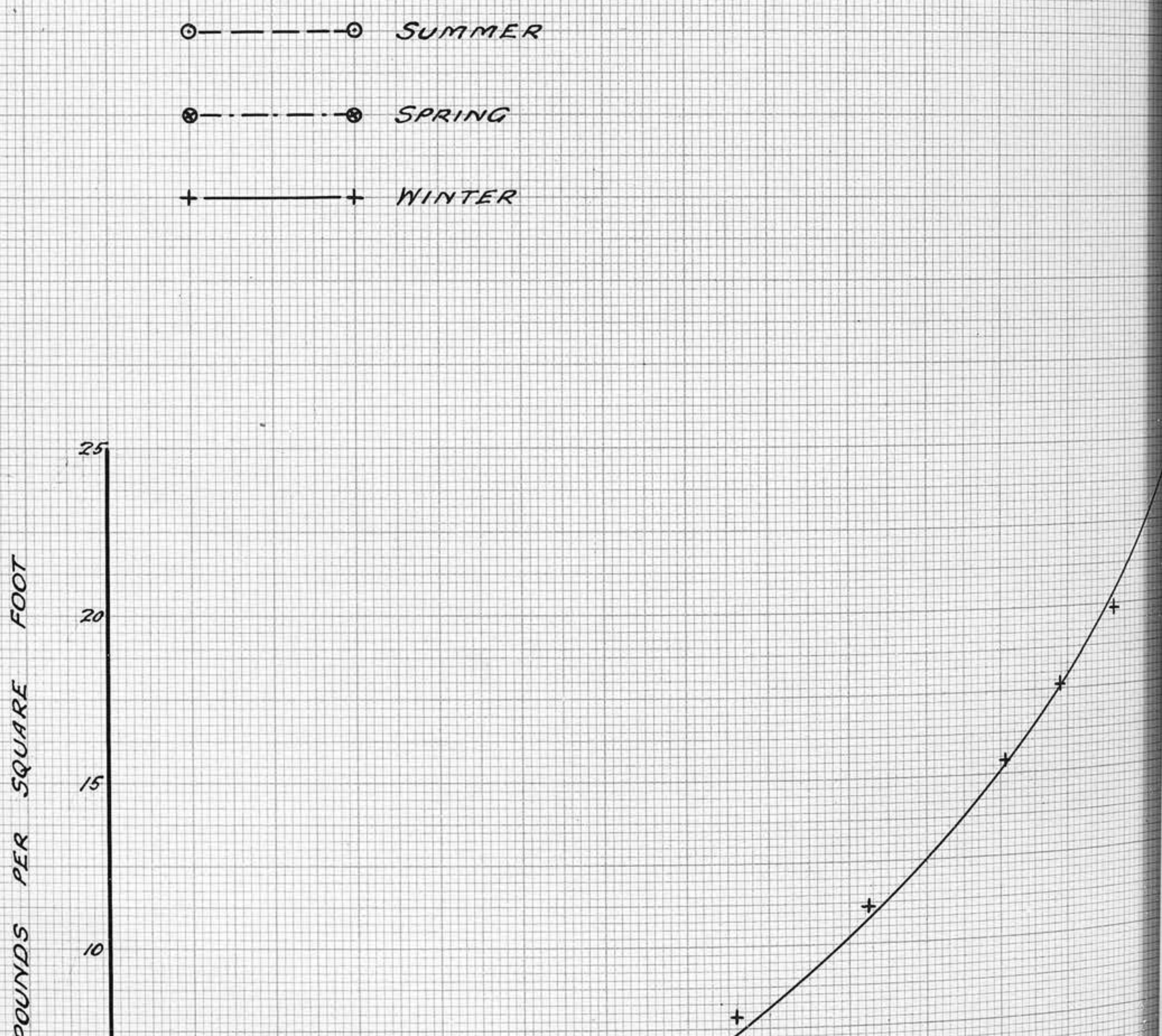
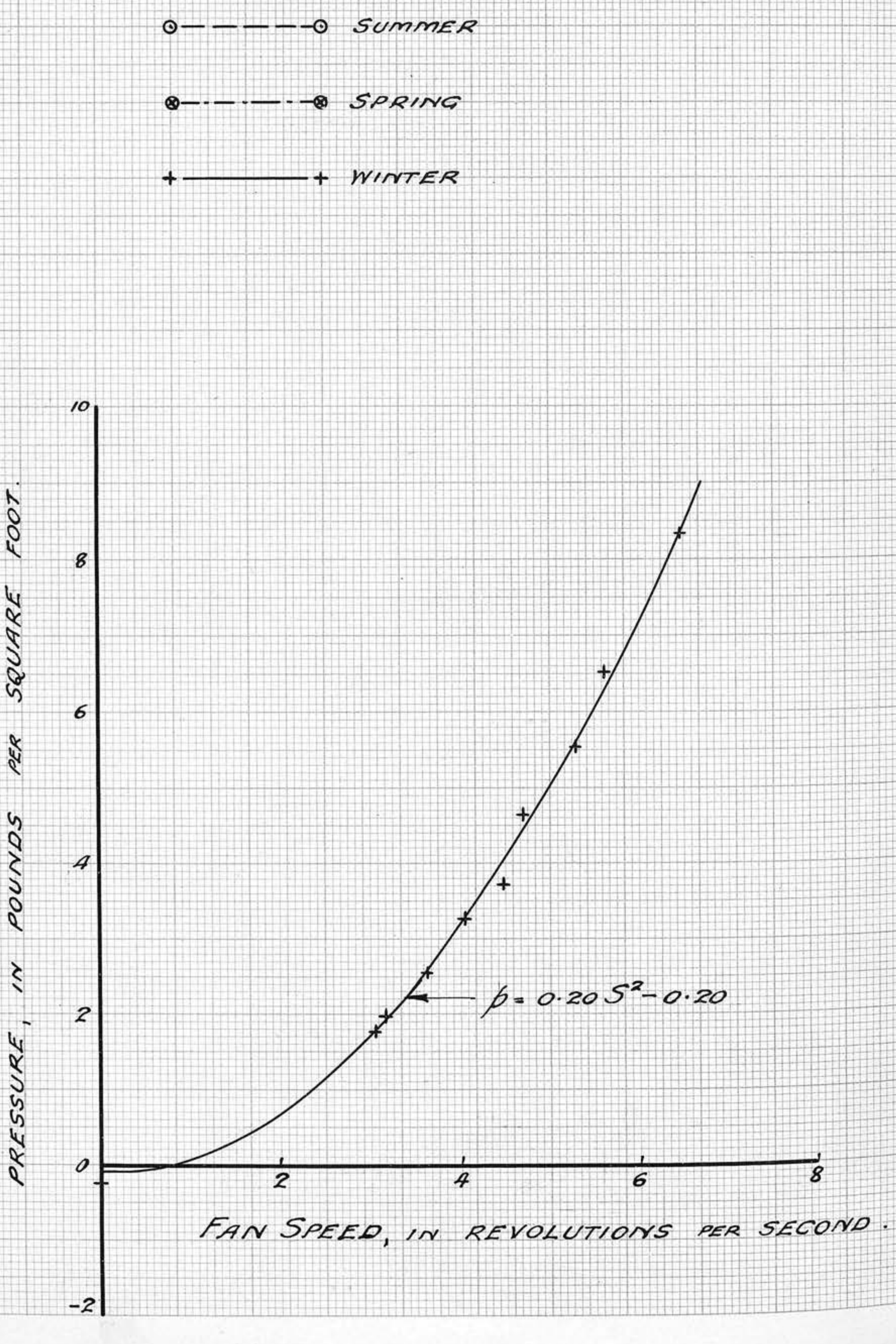


FIGURE 72.

CRAVEN COLLIERY.



(3) If not quite so important as those already discussed, the relationship, $p \propto S^2$, is well worth some consideration from the mining engineer who is connected with the ventilating system. When the relation discussed in the last section is not known, by the use of this relation and the equation of the mine characteristic, the fan speed required to cause a certain quantity of air to circulate in the mine can be predetermined. From this fact springs its importance. To obtain some information regarding this relationship at mines, fan-drift pressures and fan-speeds, measured as already described, were plotted, the former as ordinates, and the latter as abscissae. The graphs so obtained are shown in Figures 61-72 inclusive. The anomalies, already mentioned and discussed (see Section (1)) are again noticed. One curious fact stands out, - there is apparently no "kink" in this set of curves. It seems strange that the "kink" should be an attribute of the quantity alone, but, from an examination of the graphs this appears to be the case. One again begins to suspect the anemometer, but, after again considering the points raised in its defence in Section (1), one must clear the anemometer from all suspicion and accept the rather remarkable fact.

<u>The Equation of the Fan-drift Pressure - Speed Curves.</u>

It is seen from the graphs, that due to natural ventilation, curves passing through the observed points do not pass through the origin. From the shape

Table IV. - The Most Suitable Type of Equation for the Pressure-Speed Curve.

No.	Name of Colliery.	Period of Year.	Mean temperature of external air in degrees Fahrenheit.	Type of Equation. $p = H S^2 + I.$	Accuracy of the Equation.
1	Arniston	Winter	41.27	$p = 0.65 S^2 - 0.52$	Good
		Spring	48.63	$p = 0.68 S^2 - 0.48$	Good
		Summer	57.93	$p = 0.665 S^2 - 0.30$	Good
2	Easthouses	Winter	35.03	$p = 0.06 S^2 - 1.06$	Fair
		Spring	51.17	$p = 0.06 S^2 - 0.35$	Good
		Summer	57.70	$p = 0.07 S^2 - 0.125$	Good
3	Polkemmet	Winter	46.64	$p = 2.00 S^2 - 0.40$	Fair
		Spring	57.79	$p = 1.92 S^2 - 0.42$	Good
4	Preston-links	Winter	39.95	$p = 2.07 S^2 - 0.27$	Fair
		Spring	44.92	$p = 2.01 S^2 - 0.12$	Fair
		Summer	65.50	$p = 2.40 S^2 - 0.40$	Fair
5	Dunnikier	Winter	37.90	$p = 6.93 S^2 - 0.03$	Good
		Spring	46.85	$p = 6.73 S^2 - 0.03$	Good
		Summer	60.65	$p = 6.91 S^2 - 0.18$	Good
6	Kinglassie	Winter	40.70	$p = 4.56 S^2 - 0.02$	Good
		Spring	44.98	$p = 4.82 S^2 - 0.02$	Good
		Summer	58.75	$p = 4.85 S^2 + 0.02$	Good
7	Valleyfield	Winter	33.64	$p = 3.85 S^2 - 0.75$	Poor
		Spring	49.80	$p = 4.78 S^2 - 0.33$	Poor
		Summer	63.25	$p = 3.52 S^2 + 0.03$	Poor
8	Wellesley	Winter	35.75	$p = 4.95 S^2 - 0.30$	Good
		Spring	44.26	$p = 2.46 S^2 - 0.33$	Good
		Summer	65.00	$p = 4.72 S^2 + 0.13$	Good
9	Hylton	Winter	35.40	$p = 1.09 S^2 - 0.81$	Good
10	Silksworth	Winter	36.16	$p = 2.08 S^2 - 1.37$	Fair
11	Coventry	Winter	41.30	$p = 4.54 S^2 - 0.16$	Poor
12	Craven	Winter	37.23	$p = 0.20 S^2 - 0.20$	Good

of those graphs, an equation of the form $p = HS^2 + I$ (or a more complicated form) is suggested, where I denotes the effect of natural ventilation and H is a coefficient. More complex forms were tried, but the slightly increased accuracy so gained does not warrant the added complications due to the extra terms of the equations. The most suitable equations of this type for the curves (Figures 61-72) are as shown in Table IV. For all practical purposes those equations seem to be quite satisfactory and suitable. It would then seem justifiable to say that $p^1 = p \pm I = HS^2$. i.e. the fan-drift pressure when the fan is running, plus or minus the fan-drift pressure (the α term really) when the fan is stopped, (the sign depending upon whether natural ventilation does or does not assist the fan) is proportional to the square of the speed.

(4) A matter of some importance to the fan designer and the fan-user is the resistance of the fan. This is not a constant but varies, depending upon the fan-speed. The most important value of this resistance is that when the fan is running at normal speed. Unfortunately, it is not at all easy to measure the resistance of a fan running at any speed. Even when the fan is stationary, however, the resistance is of some interest, as it allows a comparison to be drawn between the resistances of various types. It seems more than probable, also, that the types of fans with the lower resistances when stationary will still be in

TABLE V. - RESISTANCES of STATIONARY FANS.

No.	Name of Colliery.	Type of Fan.	Diameter in inches.	Width in inches.	Pressure in pounds per square foot.	Air-volume in kilocusecs.	Resistance of Fan in Atkinsons.
1	Arniston.	Sirocco (Double inlet)	77	63	0.83 0.82 0.61 0.55 0.40 0.21	0.635 0.637 0.531 0.477 0.438 0.306	2.05 2.02 2.16 2.42 2.08 2.25
2	Easthouses.	Propeller (Sirocco)	70	-	1.10 1.05 0.39 0.34 0.14	0.436 0.423 0.266 0.251 0.156	5.78 5.83 5.23 5.40 5.76
3	Polkemmet.	Sirocco (Double inlet)	105	84	0.24 0.23 0.255 0.26	0.806 0.837 0.795 0.804	0.37 0.33 0.41 0.40
4	Preston-links.	Howden (Double inlet)	156	81	0.22 0.24	0.372 0.353	1.59 1.92
5	Dunnikier./ Waddle						

TABLE V. - RESISTANCES of STATIONARY FANS (Continued).

No.	Name of Colliery.	Type of Fan.	Diameter in Inches.	Width in Inches.	Pressure in pounds per square foot.	Air-volume in kilocusecs	Resistance of Fan in Atkinsons.
5	Dunnikier.	Waddle (Single Inlet)	318	12	0.14	0.205	3.33
7	Valleyfield.	Walker (Double Inlet)	216	84	0.12 0.13 0.16 0.12	0.644 0.644 0.471 0.463	0.29 0.31 0.61 0.56
8	Wellesley.	Waddle (Single Inlet)	252	16	0.11 0.13 0.18	0.593 0.569 0.577	0.31 0.40 0.54
9	Hylton.	Sirocco (Double Inlet)	91	63	1.23 1.35	1.151 1.200	0.93 0.94
10	Silksworth.	Capell (Double Inlet)	144	72	0.33	0.97	0.36
12	Craven.	Sirocco (Double Inlet)	49	45	0.24 0.23	0.210 0.192	5.44 6.23

that category when running.

To investigate this matter to some slight extent, the resistances of the fans (when stationary) were evaluated at the Collieries visited. It is thought that the relation $p \propto Q^2$ will hold when air is passing through a fan. When fans at pits are stopped, natural ventilation usually causes air to circulate through the mine and through the fan. If the upcast doors are kept closed and surface leakage be avoided, by measuring the natural ventilating pressure, p_f, which forces a certain quantity of air, Q_f, through the stationary fan, from the equation $p_f = R_f Q_f^2$, R_f, the resistance of the fan and the fan-drift to the point of pressure measurement, can be calculated. As the resistance of this part of the fan-drift is negligible, the resistance of the fan, when stationary, is thus found.

The resistances of the fans (when stationary) at the collieries at which the described tests were run were calculated in this way; the values found are given in Table V. In all cases, the measurements were all of a very small order, and in some cases, so small that they had to be neglected, as no great weight could be put on their accuracy. However, as many values as possible have been included in the table. Due to this difficulty in measurement and the fact that the measurements belong to the unstable zone, some variation exists in the values calculated for the resistance of each fan, e.g.at Valleyfield Colliery.

Nevertheless, some interesting points are demonstrated. It is seen that the stationary fans have resistances which are by no means unimportant. Indeed, in some cases, e.g.at Craven Colliery, the values are astonishingly high, especially when compared with the usual conceptions of the values of mine resistances. As might be expected, the figures show that, considering fans of the same type, the smaller the fan, the higher is its resistance. For instance, the 49 inch diameter Sirocco fan at Craven Colliery has a resistance of about 5.8 Atkinsons; the fan at Arniston Colliery (a 77 inch diameter Sirocco), a resistance of 2.2 Atkinsons approximately; a similar fan (91 inch in diameter) at Hylton Colliery, a resistance of 0.94 Atkinsons; while the resistance of the 105 inch diameter Sirocco fan at Polkemmet Colliery is about 0.81 Atkinsons. All those are of the double-inlet type of Sirocco fan. If this comparison is carried to the Waddle fans at Dunniker and Wellesley Collieries, it would appear that the smaller the diameter of this type, the lower the value of the resistance. It must be mentioned, however, that in the former case the fan was in a very bad state, being coated with slime and mud, and being dragged through a pool of water on the floor of the drift. The high resistance calculated for the propeller fan at Easthouses Colliery is very surprising, but again there are peculiar circumstances. To pass through the fan at this mine, the air has to negotiate two right-angle bends; in addition, surface leakage would probably be fairly high.

Even allowing for the difficulties in evaluating this quantity, it would thus appear that a fan has a very appreciable resistance, which may reach extravagant values, if care is not taken in installing the fan and keeping it in repair. In many cases, it would seem that much power is being lost at colliery ventilating plants by this high resistance. Much of this loss is sometimes unnecessary, and often due to neglect.

(5) Natural Ventilation may be likened to a second fan operating in series with the surface ventilator; it has a varying affect which chiefly depends upon the difference in temperature, and so in density, between the air in the upcast and downcast shafts. If the air in the upcast shaft has the higher temperature, natural ventilation assists the fan, and the fan is opposed by this agent if the air temperature is greater in the downcast. Natural ventilation has an important effect on mine ventilation, especially in deep, hot mines, but also when the pits are shallow and cool.

Mr.Robert Clive (see Clive's Work) was really the first to give figures showing the importance of natural ventilation. His results were obtained at Bentley Colliery, Yorkshire, where, with the fan running at normal speed, 309, 530 cubic feet of air per minute

TABLE VI. - Comparison of the Air Volumes in Mines, with the Fan at Normal Speed and Stationary.

T = Average Upcast Temperature.
t = Average Downcast Temperature.

No. Name of Colliery.	Winter Test. T - t, °F.	Winter Test. Normal Fan Speed, Cubic Feet p.min.	Winter Test. Fan Stationary, Cubic Feet per minute.	Spring Test. T - t, °F.	Spring Test. Normal Fan Speed, Cubic Feet p.min.	Spring Test. Fan Stationary, Cubic Feet per minute.	Summer Test. T - t, °F.	Summer Test. Normal Fan Speed CubicFt. per minute.	Summer Test. Fan Stationary, Cubic Feet per minute.
1. Arniston.	18.21	128,850	38,150	12.43	113,110	30,250	6.30	117,055	22,300
2. Easthouses.	12.51	70,400	25,770	2.27	70,610	15,500	-	59,280	10,430
3. Polkemmet.	19.30	105,570	49,290	10.52	103,740	47,960	-	-	-
4. Preston-links.	13.85	117,750	22,340	9.54	116,940	21,180	-6.99	100,768	3,660
5. Dunnikier.	12.49	77,220	12,325	6.97	73,450	11,430	0.90	78,390	6,600
6. Kinglassie.	11.31	76,710	11,645	7.60	77,370	10,040	-1.11	76,700	18,070
7. Valley-field.	19.09	159,700	38,615	9.64	169,140	27,970	-2.36	165,900	6,380
8. Wellesley.	24.46	127,460	34,850	16.30	148,100	33,090	-2.75	121,100	9,315
9. Hylton.	22.48	173,890	70,500	-	-	-	-	-	-
10. Silksworth.	21.65	196,220	59,700	-	-	-	-	-	-
11. Coventry.	16.61	69,620	35,030	-	-	-	-	-	-
12. Craven.	13.97	31,000	12,050	-	-	-	-	-	-

were circulating through the mine system. The fan was then stopped and the upcast doors opened, when 200,000 cubic feet of air per minute was measured as passing through the mine, i.e. two-thirds of the normal ventilation was produced at this time by natural agencies. It must be noted that the upcast doors were wide open for the test. The difference in temperature between the air in the two shafts was 20° Fahrenheit.

In the colliery tests described, the fan was stopped as mentioned before and observations taken; the upcast doors were not opened but were held shut, so that the air should pass through the stationary fan. The air-volumes so obtained, together with the normal quantities and the differences in temperature between the two shafts are given in Table VI.

This Table which covers a fairly representative set of mines, shows conclusively that during the greater part of the year, natural ventilation plays an important part in mine ventilation. At Hylton Colliery, for instance, two-fifths of the total air quantity was, in the winter case, due to natural ventilation; at Coventry and Polkemmet Collieries, natural agencies produced almost half of the total volume in the corresponding cases. During the spring, - and we may reasonably add, during the autumn - natural ventilation also is an important factor. At Arniston Colliery, for instance, for the spring test, about one quarter of the total volume circulating was due to this agent. It would appear, however, that during the hot summer months, no great quantity of air is circulated by natural ventilation. At Easthouses Mine, the volume found was about one-sixth of the normal. This mine, however, has an underground connection with other ventilating systems, so that there is some doubt as to how much of this is actually due to natural causes. Unfortunately for this part of the work, there are several cases of such complex ventilating systems; this fact and the presence in certain instances of steam pipes in the shafts complicate matters.

Nevertheless, it can be assumed that natural ventilation is far from being negligible for about nine months of the year and generally assists the fan. The fan is a non-stop machine, and any economy gained in connection with it will have the maximum effect. Fan installations should therefore be arranged to take full advantage of the benefits bestowed by natural ventilation. For economy in power consumption, the speed of the fan should be variable to cope with variations in the air quantity due to natural effects. When the fan is driven by a steam-engine or variable speed motor, the problem of this variation is simple; when a constant speed motor is used, mechanical difficulty arises. The ideal arrangement, not yet attained so far as the writer knows, would be to have an automatic speed variation, worked mechanically from the fan drift.

Factors controlling Natural Ventilation in Mines. - Natural Ventilation would be an easily determined quantity, were it merely an effect of the shafts; it is, however, influenced more or less by the workings of the mine. The existence of inclined workings in one or more of the seams wrought complicates matters; generally, the influence of those workings is too great to be neglected, while in certain cases, it is the dominant factor. A ventilating system lying to the dip side of the shaft bottoms augments natural ventilation, while such a system lying on the rise side diminishes it. This type of ventilation is called natural because its presence is due to natural rather then artificial agencies, but the natural forces are modified to some extent by factors artificially created. Primarily the difference in density of intake and return air is due to heat and moisture picked up from (sometimes given up to) surfaces with which the air comes into contact on its passage through the mine, but also to a lesser extent, to gas exuding therefrom, and to oxidation. This difference, and consequently the natural ventilating effect, varies to a considerable extent as the result of seasonal and diurnal changes in the surface atmosphere.

Those variations are not the only ones, however; the fan to a smaller extent modifies natural ventilation in the following ways -

(a) The fan greatly increases the volume and velocity of air passing through the mine, thus cooling the rock surfaces, and deepening the zone of the cooled ground. The increased velocity has the effect of slightly increasing the difference between the temperature of the surfaces and that of the air itself. In a large mine with a flat seam, the effect of increased air supply will probably be slight as the air-ways will be long enough to ensure that the temperature, etc.of the upcast air is practically unaffected thereby. If, however, there are lårge workings lying to the dip, the effect will be to increase the natural ventilating pressure by cooling the intakes; while the opposite effect would be probable with a mine at an early stage of development or with extensive workings to the rise.

(b) In the case of an exhausting fan (the argument holds good for a forcing fan as well) working on a mine, a reduction of pressure is caused in the upcast shaft, reducing the density of air there and so increasing the natural ventilating pressure. This drop in pressure also affects the air-ways, but as the correction is always small, the effect on the air in the air-ways can be neglected. In every mine at which the tests were carried out, the shaft resistances were small in comparison with the resistances of the workings; neglecting shaft resistance, it can be assumed that the fan-drift gauge (p,pounds per square foot) measures the difference of pressure between the upcast shaft as a whole and the downcast as a whole. Normal atmospheric pressure being 2,120 pounds per square foot, W_u pounds, the mean weight of a cubic foot of upcast air, and D feet, the depth of the shaft, the slight rarefaction produced by the fan gives a positive correction (β_1), evaluated by the formula -

$$\beta_1 = \frac{p\ W_u\ D}{2{,}120} \quad \text{pounds per square foot} \ldots.(1)$$

For most purposes, it will be accurate enough to take β_1 as equivalent to 0.035 for every pound per square foot of pressure per 1,000 feet of depth.

(c) As the air circulates through the mine, the volume becomes greater due to increased temperature and moisture content, as well as, to some extent, the exudation of mine gases. The increase in volume may be about 15 per cent, so that provided both shafts are of the same cross-sectional area, there must be an increase in velocity in the upcast shaft, compared with the downcast. Upcasts are generally smaller than downcasts, so that the velocity is further increased. Hence, due to the excess air-velocity in the upcast shaft compared with the downcast, the upcast air has a lower static pressure. As static pressure is a factor controlling air density, another correction is required. This correction (β_2) may generally be neglected, however.

$$\beta_2 = \frac{W_u^2\ (V_u^2 - V_d^2)\ D}{4{,}240\ g} \quad \text{pounds per square foot} \ldots\ldots.(2)$$

where V_u and V_d are the air velocities (in feet per second) in the upcast and downcast shafts respectively. For shafts 1000 feet deep, in which the velocities are respectively 25 and 12.5 feet per second, β_2 is only 0.02 pounds per square foot. If then α represents Professor P.J.Daniell's[1] "thermal head" or the major component of the natural ventilating pressure - the part which alone would be effective if the fan were stopped, - when the fan is running,

Natural Ventilating Pressure $= \alpha + \beta_1 + \beta_2$ ...(3)

in which, α may be negative, especially under summer conditions.

Measurement of Natural Ventilation. - In the case of dead flat seams, this measurement can be effected by finding the air densities in the upcast and downcast shafts, and multiplying their difference by the depth. This method can seldom be used, and in most cases some more general means must be employed. Several methods, all assuming that underground fans are shut down for the period of test, will be given.

(a) An air-density survey extending throughout the workings may be employed to calculate the natural ventilating pressure, but this method seems impracticable, especially for complex ventilating systems, as, for example, at Wellesley Colliery. In this case, there are underground connections to other pits, main

[1]Trans.Inst.M.E., 1925-1926 LXXl, p.39.

returns at various levels in the upcast shaft, etc. In any mine in the time required to complete such a survey with a few observers, natural ventilation would certainly vary.

(b) Murgue used a more convenient method at Créal Colliery in 1872.[1] He stopped the fan, temporally closed the fan-drift by a barrier "to allow the natural action to press with all its force against that obstruction"; he then read the difference of pressure on the two sides of the "obstruction" by a water-gauge. It was considered by Murgue himself that this pressure exceeded the true value by about one-fifth. As he based his criticism upon the equivalent orifice, depending on the "square law" even for the lower part of the characteristic curve, his argument is open to doubt. He measured 4 mm.and from the known equivalent orifice of the mine, calculated 3.3; hence his figure of one-fifth.

One or two points regarding this method must be observed -

(1) The figure obtained by this method is the α term already mentioned. When the fan is running, the correction β_1 (eqn (1)) must be applied; β_2 is negligible.

(2) Surface leakage will tend to give low readings and should be prevented as far as possible.

(3) The "obstruction" in the drift should be completed immediately after stopping the fan and the

1 "Essai sur les Machines d'Aerages". Bull Soc.

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[1] "Essai sur les Machines d'Aerages", Bull.Soc. Indus.Min., series 2, 1873, vol.11, p.464.

water-gauge reading taken within a few minutes after this, so that the air-temperaturesin the mine have not had time to alter to any great extent.

(4) Where the mine workings are approached from the shaft by roadways at different levels, the closing of the fan-drift does not stop ventilation; the air in the upper seam reverses and a closed underground circuit is set up.

(c) In a recent article Professor Henry Briggs[1] suggested a method. He proposed to set the doors, etc. at the fan for reversal of the air current, and to slowly increase the fan-speed from zero until the air in the upcast became stationary. A reading of the reversed gauge in the drift would give the required value, because the fan had neutralized natural ventilation. This method has the advantage of being unaffected by surface leakage if the tests for stagnation are carried out in the shaft, and not in the fan-drift.

This last method requires very close speed regulation at low speeds. To avoid this, the result could be obtained by opening the mouth of the upcast, reversing the ventilation with the fan-running at a reduced speed, say, at half speed, and then gradually closing the shaft-mouth until the air is stagnant in the lower part of the upcast shaft. At that moment the difference between the pressure in the shaft and

[1] "Fan Problems", Coll.Eng.1925, vol.11.

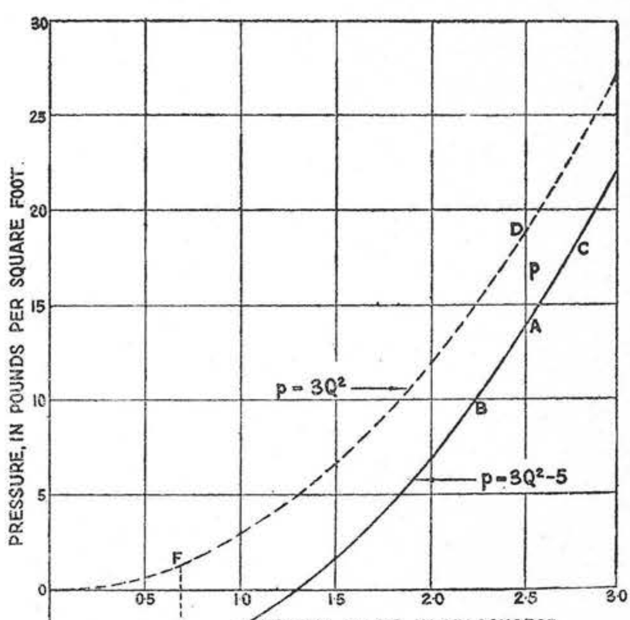

FIGURE 73.- GRAPH ILLUSTRATING EFFECT OF NATURAL VENTILATION.

that of the outside atmosphere is the value required.

With the fan running, the correction β_1 must be added. This method is also unsuitable when there are connections to the shafts at different levels.

(d) There are now to be discussed some methods due to the fact that natural ventilation causes a shift in position of the characteristic curve. J. Bouvat-Martin[1] in 1915 and Dr.J.Parker in 1924 (see Parker's Work) dealt with this influence of natural ventilation: both of those writers were ignorant of the "kink" in the curve (see Section (1)), and both took the equation of the curve to be $p = RQ^2$, when natural ventilation was absent. Parker realised that this relation was only approximate, but Bouvat-Martin regarded it as an invariable rule. This has been discussed in a previous section (see Section (1)).

Figure 73 demonstrates Bouvat-Martin's method of ascertaining the natural ventilating pressure. The upper curve ($p = 3Q^2$) is taken to be the mine characteristic when natural ventilation is absent; the lower curve ($p = 3Q^2 - 5$), that when the natural ventilating pressure exerts a force of 5 pounds per square foot. The curve has been lowered by a vertical distance of 5 units, i.e., the amount of natural ventilating pressure, without altering its shape.

If p_o be taken as the natural ventilating pressure, all ordinal intercepts, for example AD, FG, OF, etc.are

[1]"Etude sur l'Aerage des Mines" Bull, Soc.Indus. Min., series 5, 1915, vol.Vll, p.5.

equal to each other and to p_o. Suppose the point A represents the normal operation of the fan. Bouvat-Martin's instructions are, first, to determine the fan-drift pressure and quantity (p_1 and Q_1) when the fan is running at a point, such as B, with reduced speed; secondly, to get the equivalent figures (p_2 and Q_2) with the fan running, as at C, with increased speed, and then to calculate the natural ventilating pressure from the formula -

$$p_o = \frac{p_2 Q_1^2 - p_1 Q_2^2}{Q_2^2 - Q_1^2},$$ which is obtained by eliminating R between the equations $p_1 = RQ_1^2 - p_o$ and $p_2 = RQ_2^2 - p_o$.

This method may be useful if $p = RQ^2$ is an accurate enough representation, when the natural ventilating pressure is zero.

(e) Professor Henry Briggs[1] suggested a method exemplified by D. and J.S.Penman's observations at Wellesley Colliery in 1924. Those observations gave ten points on the characteristic curve. It was considered that a criterion would be obtained by extrapolation to the vertical axis, the value at which the curve cut the axis being considered the figure denoting the natural ventilating pressure. This would really give the α term were it not for the fact that there is a "kink" in the characteristic curve, which flattens out at the lower part. In the Wellesley case, the equation,

[1] Coll.Eng.1925, vol.11, p.247.

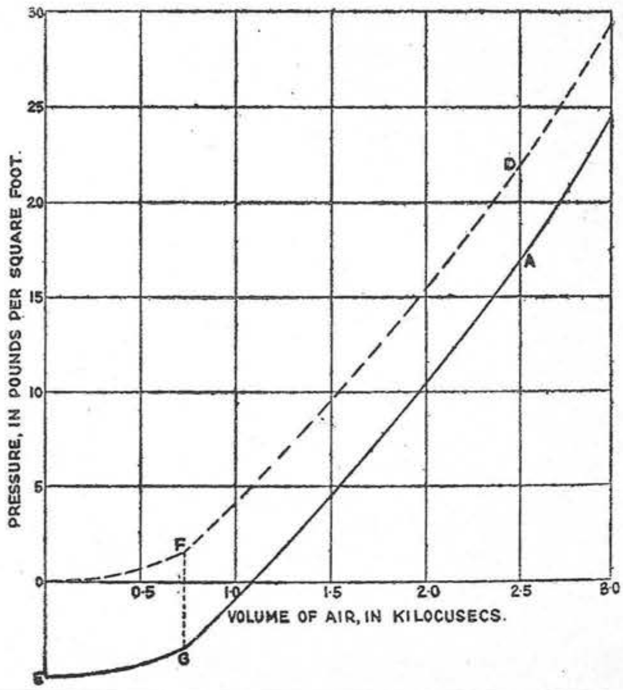

FIGURE 74. – GRAPH ILLUSTRATING EFFECTS OF NATURAL VENTILATION.

$p = 1.28\ Q^2 + 5.83\ Q - 5.33$ very nearly touched all the points; it was considered that the natural ventilating pressure was given by the last term, viz. 5.33; actually the α term was less than 5.33 pounds per square foot.

This method of extrapolation to the **Y** axis is inadmissible when the observed points all lie on the upper part of the characteristic curve. If points are obtained on the flattened portion of the curve, extrapolation may be used, but only if natural ventilation is small, e.g. in the Prestonlinks summer case, (Figure 26). Even more satisfactory is the Wellesley summer case (Figure 30) as natural ventilation slightly opposed the fan and the curve crosses the axis without extrapolation. With a winter curve, as the points lie further away from the axis, extrapolation is riskier, with a corresponding lack of faith in the result. This extrapolation method would seem to have a limited application, but may be quite useful in some cases.

It should be noted that points to the left of the **Y** axis can be obtained at the mines by reversing the air current; this, however, forces cold fresh air down the upcast shaft, completely altering the conditions. On this ground, it is inadmissible.

(f) In Figure 74, OFD and EGA are better representations of the mine characteristics, when natural ventilation is absent and when it is present to the amount AD. Approximately, the natural ventilating pressure corresponding to a given air quantity can be found by taking the distance between the curves (e.g.

AD) along the ordinate representing that value of Q i.e. the curves alone, without their equations, are sufficient for this measurement. As in Bouvat-Martin's method, it is assumed that the natural ventilating pressure is constant and is independent of the fan speed: AD, FG and OE are therefore assumed equal.

For the brief period of test required, the α term (equation (3)) may be rightly regarded as fairly constant. If the intercepts had been concerned solely with the "thermal head", and the simple case of workings in a single flat seam had been taken, the pair of curves in Figure 74 could be expected to have a constant vertical intercept from end to end, as shown. In none of the pits, at which the tests described were carried out, does this state of affairs exist. Even in the simple case mentioned, however, the β_1 correction, which increases as the quantity increases varies the intercepts. This factor is due to the slight rarefaction of the upcast air due to the fan's suction, and its value is given by equation (1). Even in shallow shafts it is seldom negligible at normal fan speed. At Prestonlinks Colliery, where the shafts are 400 feet deep, β_1 is 0.13 to 0.15; at Wellesley Colliery, (shafts 1,513 feet deep), it is from 1.2 to 1.6, while at Coventry Colliery, (shafts 2,138 feet deep), it is as much as 1.35 pounds per square foot under winter conditions.

In Figure 74, the upper curve represents the conditions when $\alpha = 0$; that is, if the fan stops, the air current is nil. Yet, when the fan is running at normal speed, as at D, β_1 is present although α is not, and the natural ventilating pressure which includes both of those, is no longer zero. The intercepts AD would have measured the natural ventilating pressure for A, only if the natural ventilating pressure for D had been nil. As the natural ventilating pressure for D is not nil, a diminution of the fan drift water-gauge is produced for that point, i.e. the ordinate of the point is shortened. To obtain the natural ventilating pressure for A, it is necessary, then, to measure AD and add the correction β_1 for D to that value.

Any proposal to use any of the methods as given under headings (d), (e) and (f) for measuring the natural ventilating pressure is brushed aside by a glance at the actual curves (Figures 23-34) obtained in the tests. The arrangement (of the curves) discussed in this section seems to form the exception, rather than be the rule. Various factors may be blamed for this; those have been mentioned in section (1). Again, there is seen the urgent need for the further investigation previously suggested.

Part 111.

C O N C L U S I O N S .

(a) There is a break in the continuity of the mine characteristic curve. The "kink" so formed is probably due to the dominant resistance of some part of the mine, probably of the main return airways.

(b) The relationship between the fan-drift pressure (p) and the air-volume (Q) cannot be represented by equations of the types, $p = \rho Q^2$ and $p = \rho Q^n$. This relation can be well shown however by equations of the types, $p = AQ^2 + BQ - C$ and $p = \rho Q^n - C$, but the most useful form is $p = \rho Q^2 - K$, which gives a good approximate representation. So the orthodox relation $p \propto Q^2$ requires modification.

(c) The resistance (R) of a mine can probably be evaluated by first measuring the α term of the natural ventilating pressure, preferably by the method used by Murgue at Créal Colliery in 1872; by taking the quantity (Q) and the pressure (p) in the fan-drift at normal fan speed, and, then by applying the formula,

$$R = \frac{p + \alpha}{Q^2}.$$

(d). The relationship between the quantity (Q) and the fan-speed (S) can be represented by equations of the form, $Q = FS + G$. The orthodox relation $Q \propto S$ is therefore generally useless.

(e) The relationship between the fan-drift pressure (p) and the fan-speed (S) can be represented for all practical purposes by equations of the form/

form, $p = HS^2 + I$. The orthodox relation ($p \propto S^2$) is again found of little value.

(f) Fans in general have very appreciable resistances. Lack of attention may allow this resistance to become very great.

(g) Natural Ventilation plays an important part in mine ventilation, especially for the colder periods of the year.

(h) The Natural Ventilating pressure $= \alpha + \beta_1 + \beta_2$

(i) The best method of evaluating the α term mentioned above is that which was used by Murgue at Créal Colliery in 1872.

APPENDIX.

The Observations: Booking and Reduction.

The procedure at the mines at which the tests were made has been indicated; it now remains to give the observations recorded and to show in what manner they were used. Below are given some observations as actually recorded by the observers at Silksworth Colliery.

Water-gauge Observations: Silksworth Colliery, Sunday, December 20th, 1925.

No. and duration of test.	Fan Speed: Readings. Revolutions per minute	Fan Speed: Average Speed. Revolutions per minute.	Readings of inclined petrol-gauge Factor 10.1: Normal: Top tube. Inches	Normal: Bottom tube. Inches	Reversed: Top tube. Ins.	Reversed: Bottom tube. Ins.	Average difference Inches.	Remarks.
3			52.75	5.30	53.30	7.40	-	Speed constant and below normal
11.00	205		52.65	5.40	53.10	7.50	-	
to	205	205	52.10	6.10	52.75	7.60	46.205	
11.20	205		52.30	5.70	52.90	7.50	equivalent	
a.m.			52.50	5.40	53.10	7.30	W.G., 4.6205	

Booking and Reduction of Anemometer Results; Silksworth Colliery, Sunday, December 20th, 1925.

No. of Test.	Anemometer readings. Actual readings for 3 minutes. Feet.	Average reading for 1 minute. Feet.	Correction Feet per minute	Average corrected reading. Feet per minute.	Remarks.

Anemometer readings.

No. of Test.	Actual readings for 3 minutes.	Average reading for 1 minute.	Correction Feet per minute.	Average corrected reading. Feet per minute	Remarks.
3	2,527 2,437 2,443	823	+8.0	831	Area at point of measurement. 202.71 square feet.

Barometer and Hygrometer Observations.

Barometer. Inches of Mercury	Hygrometer. Dry-bulb Degs. Fahr.	Wet-bulb Degs. Fahr.	Time of observation	Place of observation.	Remarks.
28.76	37.2	37.0	8.45 a.m.	Top of downcast shaft.	Taken at surface, raining.
28.30	60.0	60.0	9.07 "	Top of upcast shaft.	In fan-drift.
30.72	48.1	44.0	9.30 "	Bottom of downcast shaft. Hutton Seam.	Fan running.
30.20	74.1	66.0	9.42 "	Bottom of upcast shaft. Hutton Seam.	Fan running.
etc.	etc.	etc.	etc.	etc.	etc.

Later, values obtained by obvious methods, from observations such as the above were incorporated in the following table, which constitutes a summary. From this table, the various curves for Silksworth Colliery (Figures 32, 35, 45, 57 and 70) were plotted.

Silksworth Colliery, Co.Durham.
20th December, 1925.

Fan:- 12 ft.diameter, Capell - double inlet - steam or electrically driven.

No. of Test.	Fan Speed R.P.M.	Fan Drift Pressure. lbs. per sq. ft.	Air Measurements. Velocity, ft.min.	Volume in kilocusecs	Remarks.
1	246	33.44	968	3.270	Normal speed
2	0	-0.33	287	0.970	
3	205	24.03	831	2.808	
4	190	19.58	770	2.601	
5	181	18.30	745	2.517	
6	172	16.22	706	2.385	
7	97½	3.53	486	1.642	
8	108	5.51	529	1.787	
9	122.5	7.64	560	1.892	
10	146	10.41	615	2.078	
11	160	13.54	668	2.257	
12	0	-0.06	302	1.020	

The barometer and hygrometer readings were arranged for each of the places at which they were taken. As, for example:-

Bottom of Downcast Shaft (Hutton Seam).

Hygrometer. Dry-bulb Degs. Fahr.	Hygrometer. Wet-bulb Degs. Fahr.	Barometer. Inches of mercury.
48.1	44.0	30.72
48.8	44.4	30.725
48.9	44.3	30.60
48.7	44.2	30.55
Average 48.625	Average 44.225	Average 30.649

From Marvin's tables of "Pressures of Aqueous Vapour and Relative Humidity" in the "Smithsonian Meteorological Tables" (see Hay's Work), the Vapour Pressure, Dew Point and Relative Humidity were obtained for each point of observation. From those, the weight of 1 cubic foot of air at each point was calculated from the formula,

$$w = \frac{1.3255\ (B - \frac{3}{8} f)}{459 + t}$$

where w = weight of 1 cubic foot of air in pounds,
B = Barometric pressure in inches of mercury,
f = vapour pressure in inches of mercury,
and t = temperature of the air in degrees Fahrenheit.

The averages of those densities obtained at different parts of the upcast and downcast shafts were found, and the natural ventilating pressure due to the shafts alone was then calculated. Those atmospheric observations were also summarised in tabular form.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent.	Wt. of 1 cub. ft. air. lbs.	Place of Measurement.
36.16	35.80	28.76	35.30	96.56	0.076782	Surface
45.00	41.60	29.84	37.55	75.10	0.078256	1125 feet down D.C.
48.25	44.10	30.505	39.40	71.30	0.079476	1621 feet down D.C.
48.63	44.23	30.649	39.30	70.35	0.079795	1740 feet down D.C.
60.43 65.10/	59.93	28.30	59.63	97.39	0.071728	Fan Drift.

65.10	62.000	29.595	60.20	84.20	.074354	1121 feet down U.C.,
64.80	58.95	30.200	55.07	70.55	.076011	1616 feet down U.C.,
74.30	66.05	30.130	61.65	64.70	.074364	1734 feet down U.C.,

Calculated Natural Ventilating Pressure = 7.76 lbs/sq.ft.

From these results were plotted the graphs given in Part 11, and the equations derived were found by the usual mathematical methods.

The tabular summaries of the observations for each test are given in the remaining pages of this section.

Arniston Colliery.

24th January, 1926.

Fan:- 77 inch.Diameter Sirocco - double inlet - rope driven by D.C.Motor.

No. of Test	Fan Speed R.P.M.	Fan Drift Pressure Lbs.per sq.ft.	Air Measurements. Velocity, ft/min.	Volume in Kilocusecs.	Remarks.
1	0	-0.83	484	0.635	
2	$63\frac{1}{4}$	0.02	635	0.832	
3	$100\frac{1}{2}$	1.27	830	1.088	
4	122.8	2.20	956	1.253	
5	134	2.69	980	1.285	
6	160.6	4.20	1132	1.484	
7	186.6	5.81	1239	1.624	
8	214	7.76	1371	1.798	
9	0	-0.82	486	0.637	
10	242.2	10.07	1570	2.058	
11	255.2	11.31	1638	2.148	Normal Speed.
12	279.8	13.66	1730	2.268	

Area of Fan Drift = 78.66 square feet.

Summary of Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, inches Mercury.	Dew Point, °F	Relative Humidity, per cent.	Wt. of 1 cub.ft. of air. (lbs).	Place of Measurement
42.03	39.6	29.105	36.72	81.4	0.076783	Surface at No.1 D.C.
40.50	38.1	29.08	35.05	81.1	0.076965	Surface at No.2 D.C.
47.10	45.03	30.233	42.87	85.1	0.078911	Bottom of No.1 D.C.
45.25	43.65	29.19	42.00	88.0	0.078361	Bottom of No.2 D.C.
61.15	60.5	28.91	60.10	96.8	0.075673	Fan Drift
63.55	63.0	29.645	62.70	97.3	0.074631	Bottom of U.C.

Calculated Natural Ventilating Pressure = 2.78 lbs. per sq.ft.

Arniston Colliery.

14th March, 1926.

No. of Test.	Fan Speed, R.P.M.	Fan Drift Pressure, lbs.per sq.ft.	Air Measurements. Velocity, ft./min.	Volume. Kilocusecs	Remarks.
1	253	11.49	1438	1,885	Normal Speed
2	0	-0.61	405	0.531	
3	89¼	1.09	655	0.859	
4	27	-0.37	452	0.593	
5	58½	0.16	527	0.691	
6	115	2.03	784	1.028	
7	141¾	3.36	876	1.149	
8	168	4.96	973	1.276	
9	191.2	6.72	1075	1.409	
10	214.2	8.37	1189	1.559	
11.	228.8	9.54	1247	1.635	
12	0	-0.55	364	0.477	
13	281	14.18	1521	1.994	

Atmospheric Observations.

Dry Bulb. °F	Wet Bulb. °F	Barometer, Inches Mercury.	Dew Point, °F	Relative Humidity, per cent	Wt. of 1 cub. ft. of air. (lbs.)	Place of Measurement.
48.50	46.50	29.77	44.60	88.20	0.077466	Surface at No.1 D.C.
48.75	45.95	29.78	43.17	88.84	0.077469	Surface at No.2 D.C.
51.5	51.17	30.8	50.90	97.60	0.079609	Bottom of No.1 D.C.
51.63	48.4	30.41	45.34	79.42	0.078652	Bottom of No.2 D.C.
60.85	60.85	29.54	60.85	100.00	0.074810	Fan Drift.
64.25	64.25	30.54	64.25	100.00	0.076794	Bottom of U.C.

Calculated Natural Ventilating Pressure = 2.15 lbs. per sq. ft.

Arniston Colliery.

5th June, 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs/sq.ft.	Air Measurements. Velocity, ft./min.	Volume. Kilocusecs.	Remarks.
1	257 1/4	11.70	1488	1.951	Normal Speed
2	0	-0.40	334	0.438	
3	31 3/5	-0.18	411	0.539	
4	55 2/5	0.29	490	0.642	
5	90	1.23	634	0.831	
6	116 5/6	2.23	923	0.948	
7	141 3/4	3.47	833	1.092	
8	167 1/6	5.17	760	1.259	
9	191 2/5	6.60	1063	1.394	
10	209 2/5	8.11	1132	1.484	
11	232 1/5	9.82	1240	1.626	
12	0	-0.21	233	0.306	
13	289 3/5	14.99	1572	2.061	
14	253 3/5	11.65	1435	1.881	Normal Speed (Check)

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury.	Dew Point. °F.	Relative Humidity, per cent.	Wt.of 1 cub.ft. of air. (lbs).	Place of Measurement.
57.61	54.60	29.36	52.39	82.56	0.074990	Surface at No.1 D.C.
58.25	54.25	29.36	51.33	77.32	0.074874	Surface at No.2 D.C.
55.94	54.85	30.57	54.03	93.40	0.078275	Bottom of No.1 D.C.
55.00	51.90	30.05	49.40	81.60	0.077163	Bottom of No.2 D.C.
61.00	61.0	29.17	61.00	100.00	0.073851	Fan-Drift.
65.20	64.55	30.00	64.20	97.00	0.075710	Bottom of U.C.

Calculated Natural Ventilating Pressure = 1.13 lbs. per sq.ft.

Easthouses Colliery.
5th December 1925.

Fan:- 70 inch Diameter Sirocco Propeller - belt driven by A.C.Motor.

No. of Test.	Fan Speed. R.P.M.	Fan Drift. Pressure, lbs.per sq.ft.	Air Measurements. Velocity, ft./min.	Volume of Air in Kilocusecs.	Remarks.
1	0	-0.45	480	0.644	Upcast doors open.
2	0	-1.10	325	0.436	Upcast doors closed
3	493	3.06	874	1.173	Normal speed
4	80*	-0.89	381	0.512	
5	526	3.71	919	1.234	
6	441	2.29	789	1.059	
7	405	1.76	742	0.996	
8	350	1.09	684	0.918	
9	0	-1.05	315	0.423	Upcast doors closed
10	303	0.47	623	0.836	

Area of Drift = 80.55 square feet.
* Fan being driven by Natural Agencies.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury.	Dew Point. °F.	Relative Humidity. Per cent.	Wt. of 1 cub.ft. of air (lbs).	Place of Measurement.
35.03	32.83	29.92	30.00	79.75	0.08010	Surface.
53.50	50.00	31.40	47.85	84.4	0.081383	Bottom of D.C.
53.35	52.5	89.91	52.00	98.00	0.076991	Fan Drift.
59.20	58.60	31.40	58.24	97.08	0.080185	Bottom of U.C.

Calculated Natural Ventilating Pressure = 4.41 lbs. per sq.ft.

Easthouses Colliery.

13th March, 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift. Pressure, lbs. per sq.ft.	Air Measurements. Velocity ft./min.	Volume in Kilocusecs.	Remarks
1	484	3.82	889	1.193	Normal speed.
2	0	-0.39	198	0.266	
3	0	-0.14	255	0.342	U.C. doors open
4	524¼	4.51	936	1.256	
5	470	3.51	846	1.136	
6	365	2.23	696	0.934	
7	390	2.38	708	0.950	
8	356	2.04	660	0.886	
9	0	-0.34	187	0.251	
10	233½	0.66	460	0.618	
11	262½	0.95	500	0.671	
12	342¾	1.68	626	0.840	
13	412½	2.64	733	0.984	

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent.	Wt. of 1 cub.ft. of air. (lbs).	Place of Measurement.
51.16	48.50	29.92	46.07	82.82	0.077435	Surface.
55.81	53.96	30.91	52.55	88.97	0.079196	Bottom of D.C.
52.65	52.45	29.88	52.25	98.40	0.077041	Fan Drift.
58.86	58.31	30.91	57.95	96.37	0.078663	Bottom of U.C.

Calculated Natural Ventilating Pressure = 0.911 lbs. per sq. ft.

Easthouses Colliery.

6th June, 1925.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs. per sq./ft.	Air Measurements. Velocity. ft./min.	Volume in Kilocusecs.	Remarks.
1	0	-0.14	116	0.156	
2	522	5.07	774	1.039	
3	333	2.10	495	0.665	
4	361	2.48	543	0.729	
5	285	1.37	457	0.614	
6	0	-0.08	143	0.192	
7	480	4.13	736	0.988	Normal Speed.

Atmospheric Observations.*

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches of Mercury.	Dew Point. °F.	Relative Humidity, per cent.	Wt. of 1 cub.ft. of air (lbs).	Place of Measurements.
57.66	54.0	29.69				Surface.
54.00	54.0					Fan-drift.

* Sufficient observations could not be obtained to complete this table or to calculate the Natural Ventilating Pressure.

Polkemmet Colliery.

28th February 1926.

Fan:- 105 inch Diameter Sirocco-double inlet - steam driven.

No. of Test.	Fan Speed. R.P.M.	Fan Drift. Pressure lbs.per sq.ft.	Air Measurements. Velocity. ft/min.	Volume in Kilocusecs.	Remarks.
1	123.6	8.58	635	1.760	Normal speed
2	0	-0.21	291	0.806	
3	139¼	10.03	676	1.873	
4	116.4	7.19	591	1.638	
5	110	6.07	559	1.549	
6	105.3	5.46	542	1.502	
7	93	4.28	508	1.408	
8	81.6	3.05	476	1.319	
9	72.3	2.33	451	1.250	
10	57.6	1.52	424	1.1750	
11	43.6	0.77	401	1.111	
12	0	-0.23	302	.837	

Area of Fan Drift = 166¼ sq.ft.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury	Dew Point °F.	Relative Humidity. per cent.	Wt.of 1 cub.ft. of air. (lbs).	Place of Measurement.
46.64	44.30	29.69	41.87	83.45	0.077574	Surface.
49.20	48.10	30.87	47.10	92.60	0.080211	Bottom of D.C.
68.58	68.56	29.61	68.54	98.84	0.068534	Fan Drift.
65.87	65.22	30.88	65.02	97.3	0.077353	Bottom of U.C.

Calculated Natural Ventilating Pressure = 6.63 lbs. per sq. ft.

Polkemmet Colliery.

4th April 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift. Pressure. lbs.per sq.ft.	Air Measurements. Velocity. ft/min.	Volume in Kilocusecs.	Remarks.
1	126.2	7.85	624	1.729	Normal Speed.
2	138.½	9.74	681	1.887	
3	0	-0.26	287	0.795	
4	32	0.33	344	0.953	
5	43.3	0.72	383	1.061	
6	98	4.70	531	1.471	
7	82¾	3.35	482	1.336	
8	72¾	2.48	452	1.252	
9	110.2	6.14	573	1.590	
10	116.1	6.76	591	1.638	
11	56.6	1.38	415	1.150	
12	0	-0.26	290	0.804	

Atmospheric Observations.

Dry Bulb. ^{o}F.	Wet Bulb. ^{o}F.	Barometer, Inches Mercury.	Dew Point. ^{o}F.	Relative Humidity, Per cent.	Wt.of 1 cub.ft. of air (lbs).	Place of Measurement.
57.79	54.71	29.42	52.45	82.33	.070593	Surface.
54.71	53.79	30.87	53.12	94.62	.079254	Bottom of D.C..
73.80	73.07	29.37	72.75	96.80	.072303	Fan Drift.
59.75	58.60	30.86	57.88	93.52	.078408	Bottom of U.C..

Calculated Natural Ventilating Pressure = 1.37 lbs. per sq.ft..

Prestonlinks Colliery.

9th August 1925.

Fan:- 13 Ft.Diameter Howden - double inlet 4 steam driven.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft.	Air Measurements. Velocity. ft./min.	Volume in Kilocusecs.	Remarks.
1	0	-0.01	31*	0.061	*By smoke
2	19.5	.10	86	0.168	
3	68	2.60	469	.909	
4	47	1.58	324	.628	
5	88	4.60	604	1.171	
6	98	5.86	679	1.31	
7	109	7.59	778	1.509	
8	120	9.20	866	1.679	Normal speed.
9	132	11.20	98 0	1.901	

Area of Fan Drift = 116.36 sq.ft.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent..	Wt.of 1 cub. ft.air (lbs).	Place of Measurement.
65.50	58.45	29.64	53.55	65.60	.074720	Surface.
63.10	58.85	30.01	56.25	84.15	.075770	Bottom of D.C..
56.85	56.65	29.52	56.52	98.7	.075413	Fan Drift.
57.77	57.45	29.90	57.29	98.06	.076247	Bottom of U.C..

Calculated Natural Ventilating Pressure = 0.23 lbs. per sq. ft..

Prestonlinks Colliery.

6th December 1925.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	12	-0.10	240	0.465	Underground fans stopped.
2	$54\frac{1}{2}$	1.49	478	0.927	Underground fans running.
3	129	9.93	1012	1.963	"
4	146	12.9	1173	2.275	"
5	123	8.52	941	1.825	"
6	116	7.38	882	1.71	"
7	$105\frac{1}{2}$	5.75	757	1.468	"
8	$81\frac{1}{2}$	3.71	640	1.241	"
9	70	2.61	572	1.109	"
10	17	0.02	245	0.475	"
11	0	-0.28	185	0.359	"
12	0	-0.22	192	0.372	Underground fans stopped.

Area of Fan Drift = 116.36 sq.ft..

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury.	Dew Point. °F.	Relative Humidity, per cent.	Wt.of 1 cu.ft. of air. (lbs.)	Place of Measurement.
39.95	37.0	30.06	32.95	75.69	.079705	Surface.
39.00	37.8	30.46	36.22	89.4	.080863	Bottom of D.C..
51.20	50.80	29.98	50.50	97.20	.077531	Fan Drift.
55.55	55.00	30.30	54.60	96.40	.077655	Bottom of U.C..

Calculated Natural Ventilating Pressure = 1.07 lbs. sq.ft.

Prestonlinks Colliery.

21st March, 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft.,	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	122¾	8.50	1005	1.949	Normal speed
2	143¾	11.53	1166	2.261	
3	0	-0.19	179	0.347	
4	69	2.62	595	1.154	
5	31 2/3	0.41	355	0.688	
6	40 2/3	0.74	412	0.799	
7	62	2.01	561	1.088	
8	53¾	1.42	504	0.977	
9	101	5.41	848	1.645	
10	80½	3.41	695	1.348	
11	112¾	6.79	960	1.862	
12	0	-0.22	190	0.368	
13	0	-0.24	182	0.353	

Note:- Two underground fans running during tests Nos.1 to 12 but stopped during test No.13.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury,	Dew Point, °F.	Relative Humidity, per cent.	Wt.of 1 cub.ft. air (lbs).	Place of Measurement.
44.92	41.83	30.42	40.63	84.83	.079770	Surface.
43.20	41.10	30.81	38.58	83.76	.081083	Bottom of D.C..
51.86	51.76	30.31	51.65	99.16	.078277	Fan Drift.
55.35	54.87	30.75	54.55	96.80	.078833	Bottom of U.C..

Calculated Natural Ventilating Pressure = 0.75 lbs. per sq. ft.

Dunnikier Colliery, Fifeshire.

2nd August, 1925.

Fan:- $26\frac{1}{2}$ feet diameter Waddle - steam driven.

No. of Test.	Fan Speed, R.P.M.	Fan Drift Pressure. lbs.per sq.ft.	Air Measurements. Velocity. ft./min.	Volume in Kilocusecs.	Remarks.
1	59	6.58	603	1.306	Normal speed
2	66	7.99	667	1.445	
3	52	5.06	521	1.129	
4	0	-0.05	53*	0.110	* By smoke
5	46	3.74	447	0.970	
6	40	2.70	384	0.832	
7	31	1.45	291	0.631	
8	16.4	0.52	150	0.325	

Area of Fan Drift = 130 sq.ft.

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent.	Wt.of 1 cub.ft. air, (lbs).	Place of Measurement.
60.65	54.45	29.73	49.70	67.10	.075507	Surface.
57.85	57.2	30.22	56.80	96.00	.077391	Bottom of D.C.
59.1	56.2	29.64	54.15	84.20	.075428	Fan Drift.
61.2	60.65	30.185	60.3	97.2	.076770	Bottom of U.C.

Calculated Natural Ventilating Pressure = 0.64 lbs. sq.ft.

Dunnikier Colliery, Fifeshire.

12th December, 1925.

No. of Test.	Fan Speed, R.P.M.	Fan Drift Pressure, lbs.per sq.ft.,	Air Measurements. Velocity, ft./min.,	Volume in Kilocusecs.	Remarks.
1	55.8	5.86	594	1.287	Normal speed.
2*	0	-0.14	134	0.205	
3	62	7.56	656	1.421	
4	48.5	4.53	512	1.109	
5	43	3.60	476	1.031	
6	36.5	2.57	392	0.849	
7	29	1.54	318	0.689	
8	15.5	0.47	226	0.490	

Area of Fan Drift = 130 square feet.
*Area for Test No.2 = 92.13 square feet.

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent.,	Wt. of 1 cub.ft. of air. (lbs).	Place of Measurement.
37.9	35	29.905	32.2	79.2	.079592	Surface.
46.33	45.9	30.471	45.55	69.5	.079939	Bottom of D.C.,
50.5	50.5	29.830	50.5	100.0	.077233	Fan Drift.
58.7	58.4	30.43	58.2	98.0	.077779	Bottom of U.C.,

Calculated Natural Ventilating Pressure
= 1.58 lbs./sq.ft.,

Dunnikier Colliery.

27th March, 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	60	6.71	565	1.224	Normal Speed.
2	66	8.05	643	1.393	
3	0	-0.01	126	0.193	
4	5.6	0.03	196	0.301	
5	$15\frac{1}{4}$	0.39	276	0.424	
6	23	0.90	256	0.555	
7	29.8	1.61	320	0.693	
8	34	2.07	357	0.774	
9	40	2.97	394	0.854	
10	$47\frac{3}{4}$	4.32	470	1.018	
11	$54\frac{1}{2}$	5.54	528	1.144	
12	44	3.66	429	0.930	
13	0	-0.002	122	0.187	

Note:- For tests 3, 4, 5 and 13 Area = 92.13 sq.ft..
Other tests ... " = 130 sq.ft..

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer, Inches Mercury.	Dew Point. °F.	Relative Humidity, per cent..	Wt.of 1 cu. ft.air, lbs.	Place of Measurement.
46.85	45.06	29.481	43.23	87.52	.076969	Surface.
50.83	50.5	30.340	50.25	97.68	.078530	Bottom of D.C..
52.60	52.22	29.423	51.92	79.28	.075856	Fan Drift.
59.02	57.91	30.301	57.08	93.28	.077086	Bottom of U.C..

Calculated Natural Ventilating Pressure = 0.89 lbs./sq.ft..

Kinglassie Colliery, Fifeshire.

27th December, 1925.

Fan:- 18 ft.diameter Walker "Indestructible" - double inlet - rope driven by steam engine.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	98¼	12.27	573	1.279	Normal speed.
2	0	-0.05	95	0.212	
3	113.3	15.65	658	1.468	
4	84½	9.03	506	1.129	
5	72.8	6.79	444	0.991	
6	65½	5.51	406	0.906	
7	55	3.92	345	0.780	
8	47	2.62	287	0.640	
9	37	1.61	235	0.524	
10	27¼	0.92	186	0.415	
11	0	-0.04	79	0.176	
12	91½	10.69	554	1.236	

Area of Fan Drift = 133.86 sq.ft..

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent..	Wt.of 1 cu. ft.air, lbs.	Place of Measurement.
40.70	40.70	28.880	40.70	100.00	.076355	Surface.
54.16	52.60	29.983	51.40	90.68	.077080	Bottom of D.C..
54.33	53.90	28.750	52.80	94.88	.073850	Fan Drift.
63.16	61.66	29.850	60.77	92.22	.075269	Bottom of U.C..

Calculated Natural Ventilating Pressure = 2.26 lbs./sq.ft..

Kinglassie Colliery.

28th March 1926.

No. of Test.	Fan Speed R.P.M.	Fan Drift Pressure, lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Air Measurements. Volume in Kilocusecs.	Remarks.
1	93½	12.00	578	1.290	Normal speed.
2	0	-0.01	75	0.167	
3	45	2.77	296	0.660	
4	27	1.01	192	0.428	
5	35	1.67	225	0.502	
6	52½	3.69	331	0.738	
7	70	6.61	455	1.015	
8	60	4.77	392	0.875	
9	64 4/5	5.59	405	0.904	
10	86 2/3	10.43	554	1.236	
11	83 2/3	9.19	538	1.200	
12	75 2/3	7.37	475	1.060	

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent.	Wt. of 1 cu.ft. air, lbs.	Place of Measurement.
44.98	43.28	29.233	41.51	87.11	.076628	Surface.
55.90	54.63	30.475	53.76	92.44	.078054	Bottom of D.C..
54.87	54.67	29.147	54.55	98.72	.074773	Fan Drift.
61.16	60.1	30.347	59.45	94.14	.076847	Bottom of U.C..

Calculated Natural Ventilating Pressure = 1.60 lbs./sq.ft..

Kinglassie Colliery.

19th June, 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs./per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	0	0.07	-142	-0.317	Air-reversed but Gauge not.
2	35	1.65	199	0.444	
3	28 1/3	1.05	60	0.134	
4	47 2/3	3.05	251	0.560	
5	57 1/3	4.43	328	0.732	
6	66 2/3	5.84	386	0.861	
7	73	7.34	443	0.988	
8	81 1/2	9.31	511	1.140	
9	88	11.13	573	1.278	
10	101	13.55	626	1.397	
11	19 2/3	0.52	-40	-0.089	Air reversed, fan running.
12	0	0.05	-128	-0.286	Air reversed, but Gauge not.

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches of Mercury.	Dew Point, °F.	Relative Humidity. per cent..	Wt. of 1 cu. ft. of air. (lbs).	Place of Measurement.
58.75	56.75	29.72	55.43	88.72	0.075667	Surface.
63.46	62.18	30.84	62.02	95.24	0.077704	Bottom of D.C..
56.60	56.07	29.68	55.73	96.52	0.075869	Fan-Drift.
63.39	62.33	30.83	61.75	94.44	0.077699	Bottom of U.C..

Calculated Natural Ventilating Pressure = -0.112 lbs. per sq.ft..

Valleyfield Colliery, Fifeshire.

25th July, 1925.

Fan:- 18 ft.diameter Walker "Indestructible" - double inlet - Rope driven by Steam Engine.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	142	19.82	974	2.765	
2	125	14.06	816	2.317	
3	135	16.86	917	2.603	Normal speed.
4	106	11.56	749	2.124	
5	0	- 0.02	37*	0.106	*By smoke
6	86.5	7 .88	623	1.770	
7	68	4.72	473	1.342	

Area of Fan Drift = 170.33 sq.ft..

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent.	Wt.of 1 cu. ft.air, (lbs.)	Place of Measurement.
63.25	60.15	29.825	58.30	84.10	.075234	Surface.
64.00	61.00	31.225	59.15	84.30	.078660	Bottom of D.C..
61.60	60.75	29.630	60.23	95.52	.074943	Fan Drift.
60.93	60.06	30.105	59.52	,95.38	.076264	600 feet down U.C..

Calculated Natural Ventilating Pressure = 1.18 lbs./sq.ft..

Valleyfield Colliery.

26th December 1925.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	112.3	14.48	877	2.49	
2	0	-0.12	227	0.644	
3	152.5	23.94	1042	2.958	
4	126.3	16.14	885	2.512	
5	0	-0.13	227	0.644	
6	134.8	18.61	920	2.612	Normal speed.
7	99.5	9.36	722	2.050	
8	112.4	11.92	779	2.211	
9	770	5.21	591	1.678	
10	85.6	6.94	630	1.788	
11	63.1	3.59	523	1.485	
12	39.6	0.63	402	1.141	

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent.	Wt.of 1 cu. ft.air. (lbs.)	Place of Measurement.
33.64	33.2	29.446	32.5	95.44	.079042	Surface.
40.58	38.93	30.853	38.11	91.12	.081632	Bottom of D.C..
50.45	50.30	29.21	50.22	99.08	.075645	Fan Drift.
61.95	60.60	30.625	60.40	94.80	.077322	Bottom of U.C..

Calculated Natural Ventilating Pressure = 4.48 lbs./sq.ft..

Valleyfield Colliery.

20th February 1926.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft.	Air Measurement. Velocity. ft./min.	Volume in Kilocusecs.	Remarks.
1	131	21.22	993	2.819	Normal speed.
2	0	- 0.16	166	0.471	
3	140.4	25.13	1122	3.185	
4	89	10.32	708	2.010	
5	66	5.29	529	1.502	
6	55.5	3.80	485	1.377	
7	35.6	1.50	354	1.005	
8	21	0.50	279	0.792	
9	78¼	8.12	643	1.825	
10	102	13.95	851	2.416	
11	113	16.79	928	2.634	
12	0	-0.12	163	0.463	

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent.	Wt. of 1 cu. ft. air. (lbs).	Place of Measurement.
49.80	48.65	29.88	47.68	92.52	.077520	Surface.
50.46	50.00	30.89	48.90	94.76	.080023	Bottom of D.C..
54.86	54.13	29.555	53.57	95.42	.075839	Fan Drift.
61.46	61.07	30.576	60.85	97.77	.077362	600 ft. down U.C..
62.98	61.93	30.85	61.35	94.5	.077837	Bottom of U.C..

Calculated Natural Ventilating Pressure = 2.05 lbs./sq. ft.

Wellesley Colliery, Fifeshire.

19th July, 1925.

Fan:- 21 feet diameter Waddle - steam driven.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft.,	Air Measurements. Velocity. ft./min.,	Volume in Kilocusecs.	Remarks.
1	0	0.01	0	0	
2	54	4.00	340	0.879	
3	60.4	4.99	388	1.004	
4	69.6	6.45	426	1.102	
5	78.8	8.16	485	1.255	
6	92.4	11.50	574	1.487	
7	108.6	15.54	672	1.738	
8	117.0	18.14	721	1.863	
9	128.0	21.3	780	2.018	Normal speed.
10	137.0	24.48	845	2.185	
11	0	0.073	60*	-0.155	*By smoke.

Note:- Reversed Flow in Test No.11.
Area of Fan Drift = 155.25 sq.ft.

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent.	Wt.of 1 cu.ft.air, lbs.	Place of Measurement.
65.00	61.25	29.82	59.00	81.00	.074958	Surface.
66.50	65.00	31.13	64.22	95.88	.077929	1305 feet down D.C.,
69.25	65.80	31.305	64.00	83.50	.077991	Bottom of D.C.,
66.50	65.50	29.635	65.0	95.00	.074168	Fan Drift.
66.70	65.80	30.960	65.35	95.60	.077472	1313 feet down U.C.,
75.50	73.00	31.030	71.95	88.80	.076224	1325 feet down U.C.,
70.0	68.35	31.255	67.6	92.20	.077664	Bottom of D.C.,

Calculated Natural Ventilating Pressure = 0.85 lbs./sq.ft.,

Wellesley Colliery.

13th December 1925.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft.,	Air Measurements. Velocity, ft./min.,	Volume in Kilocusecs.	Remarks.
1	0	-0.107.	229	0.593	
2	140	25.71	872	2.256	
3	130.7	23.32	821	2.124	Normal speed.
4	122	20.58	777	2.01	
5	114.5	17.88	730	1.889	
6	106	14.84	685	1.772	
7	92.3	11.24	608	1.573	
8	78.4	8.17	526	1.361	
9	66	5.84	473	1.224	
10	52	3.35	385	0.996	
11	34	1.29	300	0.776	
12	0	-0.13	220	0.569	

Area of Fan Drift = 155.25 sq.ft.

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent..	Wt.of 1 cu. ft.air, (lbs).	Place of Measurement.
35.75	34.13	29.90	31.80	85.40	.079926	Surface.
53.50	50.50	31.46	47.90	82.00	.080856	Bottom of D.C.,
61.3	61.04	29.69	60.90	98.40	.075127	Fan Drift.
69.16	66.92	31.25	65.8	88.28	.077830	1325 ft. down U.C.,
69.0	68.0	31.43	67.55	98.0	.078269	Bottom of U.C.,

Calculated Natural Ventilating Pressure = 5.1 lbs./sq. ft.,

Wellesley Colliery.

21st February 1926.

Fan:- 119 inch Diameter Sirocco - double inlet - steam driven.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure, lbs.per sq.ft..	Air Measurement. Velocity, ft./min..	Volume in Kilocusecs.	Remarks.
1	214	29.60	913	2.468	Normal speed.
2	0	- 0.04	204	0.552	
3	177	21.85	828	2.239	
4	166½	18.58	761	2.057	
5	131.6	11.20	598	1.617	
6	108	7.85	524	1.417	
7	90	5.36	449	1.214	
8	33	0.76	252	0.681	
9	62.6	2.67	357	0.965	
10	79	4.24	416	1.125	
11	155	15.64	721	1.949	
12	0	- 0.02	178	0.481	
13	0	- 0.18	223	0.577	

Note:- In Test No.13 the air was passing through the Waddle fan - Sirocco being sealed off and standing.
Area of Fan Drift for Tests 1 to 12 = 162.22 sq.ft..
" " " " " Test 13 = 155.25 sq.ft..

Atmospheric Observations.

Dry Bulb, oF.	Wet Bulb, oF.	Barometer, Inches Mercury.	Dew Point, oF.	Relative Humidity, per cent.	Wt.of 1 cu.ft.air, lbs.	Place of Measurement.
44.25	43.50	29.750	42.76	94.00	.078086	Surface.
55.87	53.75	30.897	54.20	94.30	.079137	Bottom of D.C..
61.96	61.96	29.366	61.96	100.00	.074189	Fan Drift.
69.45	68.47	30.88	68.35	96.6	.076823	1325 ft. down U.C..
67.66	67.23	30.89	67.00	97.68	.077120	Bottom of U.C..

Calculated Natural Ventilating Pressure = 2.95 lbs./sq.ft..

Hylton Colliery, Co.Durham.

19th December, 1925.

Fan:- 91 inch diameter Sirocco - double inlet - steam driven.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurements. Velocity. ft./min..	Volume in Kilocusecs.	Remarks.
1	231	15.67	1346	2.882	Normal speed.
2	0	-1.23	538	1.151	
3	217	13.53	1302	2.785	
4	193	10.65	1166	2.494	
5	170	8.25	1100	2.353	
6	150.7	6.21	1027	2.196	
7	131	4.50	938	2.006	
8	113 1/2	2.69	838	1.792	
9	95 1/2	1.67	774	1.656	
10	68	0.39	725	1.551	
11	0	-1.35	561	1.200	

Area of Fan Drift = 128 1/3 sq.ft..

Atmospheric Observations.

Dry Bulb. °F.	Wet Bulb. °F.	Barometer. Inches Mercury.	Dew Point. °F.	Relative Humidity. per cent..	Wt.of 1 cu. ft.air. lbs.	Place of Measurement.
35.40	34.98	29.543	34.40	96.00	.079005	Surface.
48.6	44.6	30.875	40.3	72.80	.080380	Bottom of No.1 D.C..
47.25	44.75	31.66	42.15	82.6	.082593	Bottom of No.2 D.C..
60.16	57.62	29.345	55.95	86.16	.074496	Fan Drift.
72.30	64.20	30.90	59.50	64.4	.076615	Bottom of U.C..

Calculated Natural Ventilating Pressure = 8.37 lbs./sq.ft..

<u>Silksworth Colliery, Co.Durham.</u>

<u>20th December, 1925.</u>

<u>Fan</u>:- 12 ft.diameter Capell - double inlet - steam or electrically driven.

No. of Test.	Fan Speed, R.P.M.	Fan Drift Pressure, lbs.per sq.ft..	Air Measurements. Velocity, ft.min..	Volume in Kilocusecs.	Remarks.
1	246	33.44	968	3.270	Normal speed.
2	0	-0.33	287	0.970	
3	205	24.03	831	2.808	
4	190	19.58	770	2.601	
5	181	18.30	745	2.517	
6	172	16.22	706	2.385	
7	97½	3.53	486	1.642	
8	108	5.51	529	1.787	
9	122.5	7.64	560	1.892	
10	146	10.41	615	2.078	
11	160	13.54	668	2.257	
12	0	-0.06	302	1.020	

Area of Fan Drift = 202.71 sq.ft.

<u>Atmospheric Observations</u>.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent..	Wt.of 1 cu. ft.air, lbs.	Place of Measurement.
36.16	35.80	28.76	35.30	96.56	.076782	Surface.
45.00	41.60	29.84	37.55	75.10	.078256	1125 feet down D.C..
48.25	44.10	30.505	39.40	71.30	.079476	1621 feet down D.C..
48.63	44.23	30.649	39.30	70.35	.079795	1740 ft. down D.C..
60.43	59.93	28.30	59.63	97.39	.071728	Fan Drift.
65.10	62.00	29.595	60.20	84.20	.074354	1121 feet down U.C..
64.80	58.95	30.200	55.07	70.55	.076011	1616 feet down U.C..
74.30	66.05	30.130	61.65	64.70	.074364	1734 feet down U.C..

Calculated Natural Ventilating Pressure = 7.76 lbs./sq.ft..

Coventry Colliery, Warwickshire.

13th February, 1926.

Fan:- 175 inch diameter Sirocco; single inlet - rope driven by steam engine.

No. of Test.	Fan Speed, R.P.M.	Fan Drift Pressure, lbs.per sq.ft..	Air Measurement. Velocity, ft./min..	Volume in Kilocusecs.	Remarks.
1	119	17.67	306	1.160	Normal speed.
2	128	19.84	324	1.229	
3	110.8	15.40	272	1.031	
4	92.8	11.12	263	0.997	
5	76	7.82	243	0.921	
6	59.7	4.96	212	0.804	
7	43.8	2.68	199	0.755	
8	30.4	1.38	183	0.694	
9	0	-0.06	154	0.584	

Area of Fan Drift = 227.5 sq.ft.

Atmospheric Observations.

Dry Bulb, °F.	Wet Bulb, °F.	Barometer, Inches Mercury.	Dew Point, °F.	Relative Humidity, per cent..	Wt.of 1 cu. ft.air, lbs.	Place of Measurement.
41.30	38.98	29.62	36.05	81.50	.078265	Surface.
52.38	50.60	30.913	49.14	88.51	.079787	Bottom of D.C..
57.90	57.33	29.407	56.95	97.10	.074964	Fan Drift.
69.00	66.62	30.933	65.35	91.40	.077065	Bottom of U.C..

Calculated Natural Ventilating Pressure = 6.45 lbs./sq.ft..

Craven Colliery, Warwickshire.

13th February, 1926.

Fan:- 49 inch diameter Sirocco Double Inlet - Direct Driven by D.C.motor.

No. of Test.	Fan Speed. R.P.M.	Fan Drift Pressure. lbs.per sq.ft..	Air Measurement. Velocity. ft./min..	Air Measurement. Volume in Kilocusecs.	Remarks.
1	269	3.72	646	0.517	Normal speed.
2	0	-0.24	262	0.210	
3	388	8.34	861	0.689	
4	316.2	5.54	729	0.583	
5	243.2	3.27	609	0.487	
6	216.4	2.56	578	0.462	
7	190	1.99	508	0.406	
8	182 $\frac{3}{4}$	1.78	488	0.390	
9	0	-0.23	240	0.192	
10	282	4.65	663	0.530	
11	336.4	6.52	769	0.615	

Area of Fan Drift = 48 sq.ft..

Atmospheric Observations.

Dry Bulb. ^oF.	Wet Bulb. ^oF.	Barometer. Inches Mercury.	Dew Point. ^oF.	Relative Humidity. per cent..	Wt.of 1 cu. ft.air. lbs.	Place of Measurement.
37.22	35.67	29.760	33.50	86.10	.079303	Surface.
38.93	37.79	30.096	36.30	90.48	.079903	Bottom of D.C..
50.60	50.60	29.69	50.60	100.00	.076866	Fan Drift.
53.50	52.64	29.95	52.00	95.00	.077086	Bottom of U.C..

Calculated Natural Ventilating Pressure = 0.66 lbs./sq.ft..